NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION SITUATION AWARENESS

by

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June 2017

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2017	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION SITUATION AWARENESS			**5. FUNDING NUMBERS**
6. AUTHOR(S) Carl P. Beierl, Devon R. Tschirley			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number ____N/A____.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The Unmanned Tactical Autonomous Control and Collaboration (UTACC) program is a Marine Corps Warfighting Laboratory (MCWL) initiative to build a Marine-robotic collaborative infantry fire team. The impact of robotic teammates on the situation awareness (SA) of the fire team is a central concern for this program. The proliferation of SA enhancing technology to the lowest echelons of Marine infantry forces often involves a tradeoff between focused and distributed SA due to limited attention resources. UTACC seeks a means to measure SA tradeoffs due to the incorporation of robots into infantry fire teams.

This thesis reviews present models of individual and team SA that are applicable to the military infantry environment and proposes individual and team models of SA that address the unique requirements of UTACC. The authors then applied SA principles to Coactive Design in order to inform robotic design. The result is a methodology framework using interdependence analysis (IA) tables for informing design requirements based on SA requirements. Future research should seek to develop additional IA tables for the entirety of the Marine Corps infantry fire team mission set.

14. SUBJECT TERMS Unmanned Tactical Autonomous Control and Collaboration (UTACC), situation awareness, situational awareness, SA, team situational awareness, shared situational awareness, coactive design, interdependency, interdependence analysis, common ground, shared mental model, human robot interaction			**15. NUMBER OF PAGES** 129
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01-280-5500 | Standard Form 298 (Rev. 2–89) Prescribed by ANSI Std. 239–18

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UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION SITUATION AWARENESS

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Submitted in partial fulfillment of
the requirements for the degrees of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY (COMMAND, CONTROL, AND COMMUNICATIONS)

and

MASTER OF SCIENCE IN INFORMATION WARFARE SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	assistant automatic rifleman
AOA	analysis of alternatives
ADDRAC	alert, direction, description, range, (target) assignment, and (fire) control
ATC	air traffic control
AR	automatic rifleman
BAMCIS	begin planning, arrange reconnaissance, make reconnaissance, complete the plan, issue the order, and supervise activities
CAS	close air support
COA	course of action
COE	campaign of experimentation
CONOPS	concept of operations
DON	Department of the Navy
DRAW-D	defend, reinforce, attack, withdraw, and delay
EM	electromagnetic energy
EMLCOA	enemy most likely course of action
EMDCOA	enemy most dangerous course of action
FSCM	fire support coordination measures
FOV	field of view
FTL	fire team leader
HMI	human–machine interface
HRI	human–robot interaction
HQ	headquarters
IA	interdependence analysis
IERs	information exchange requirements
IFREP	in-flight report
MCPP	Marine Corps Planning Process
MCTL	Marine Corps Task List
MCTP	Marine Corps Tactical Publication
MCWL	Marine Corps Warfighting Laboratory

MEDEVAC	medical evacuation
MET	mission essential task
METT-TC	mission, enemy, troops, terrain, time, and civil
METT-TSL	mission, enemy, troops and fire support, terrain and weather, time, space, and logistics
MOEs	measures of effectiveness
MOPs	measures of performance
MOS	military occupational specialty
MOUT	military operations in urban terrain
NPS	Naval Postgraduate School
OCOKA-W	observation, cover and concealment, obstacles, key terrain, avenues of approach, and weather
OPD	observability, predictability, and directability
OSMEAC	orientation, situation, mission, execution, administration/ logistics, and command/signal
RIF	rifleman
SA	situation awareness or situational awareness
SAGAT	situation awareness global assessment technique
SALUTE	size, activity, location, unit, time, and equipment
SME	subject matter expert
SOS	system of systems
T&R	training and readiness
TA	time available
TFS	troops and fire support available
TW	terrain and weather
T&R	training and readiness
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
USMC	United States Marine Corps
UTACC	Unmanned Tactical Autonomous Command and Collaboration
UxS	unmanned system

ACKNOWLEDGMENTS

First and foremost, we would like to thank our advisors, Dr. Dan Boger and Scot Miller, for your guidance and oversight throughout this entire process. You advocated on our behalf when it was necessary, pointed us in the right direction when we desperately needed it, helped us scope the problem when we lost focus, and let us run with things when we saw opportunity. Thank you both for a rewarding experience.

We would also like to offer a special thank you to numerous individuals who have been essential to our work. Dr. Matt Johnson, your instruction on SA, interdependency, and Coactive Design has been invaluable. Thank you for your time and assistance in helping us identify how all of these pieces fit together and aiding us in identifying where our efforts should be focused. Thank you to Mike Malandra and Tony Padgett with the Marine Corps Warfighting Laboratory for the opportunity to participate in and contribute to the UTACC project. Bob Daniel, we hope our discussions on the detailed inner-workings of Marine Corps fire team dynamics have been as helpful for you as they have been for us. Finally, and most importantly, we would like to thank our families: Amanda, Emelia, Shaunna, Clara, and Timothy. We would be remiss not to recognize the sacrifices you all have made over the course of our preparing this thesis, along with the support, patience, and encouragement you have so steadfastly offered.

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I. INTRODUCTION

A. UTACC VISION, PROGRESS, AND RELATED WORK

This thesis is the seventh in a series supporting the Marine Corps Warfighting Laboratory (MCWL) development of the Unmanned Tactical Autonomous Command and Collaboration (UTACC) unmanned system (UxS). The UTACC UxS is a system of systems (SOS) consisting of robotic team members that will collaboratively operate with a team of Marines at a higher capacity as a team that far exceeds the operation of a single ground or aerial vehicle. A basic premise is that UTACC looks less like an operator controlling some type of Unmanned Aerial Vehicle (UAV), Unmanned Ground Vehicle (UGV), or combination thereof, and more like a UxS that is an integral part, a true “team member” of the larger United States Marine Corps (USMC) fire team.

The UTACC program development is using an incremental design process and similarities and overlapping material will undoubtedly exist between this thesis, preceding Naval Postgraduate School (NPS) theses, and concurrent theses. The first thesis developed concept of operations (CONOPS) for UTACC and highlighted the necessity of collaborative autonomy in the form of authentic collaboration between Marines and machines on a complementary playing field as teammates (Rice, Keim, & Chhabra, 2015). The second thesis offers a “red cell” critique of the CONOPS that analyzed the threats and vulnerabilities of the UTACC SOS, particularly those threats that were of a technological and information assurance nature (Batson & Wimmer, 2015). The third thesis utilized Coactive Design as a development method for human–robotic systems to provide design requirements that supported resiliency of the system through the flexibility of the fire team’s interdependent relationships (Zach, 2016). The fourth thesis identified measures of performance (MOPs) and measures of effectiveness (MOEs) to support the UTACC program (Kirkpatrick & Rushing, 2016). The fifth thesis conducted an analysis of alternatives (AOA) of prospective UAVs that would be capable of employment within the UTACC UxS (Roth & Buckler, 2016). The sixth thesis used those MOPs and MOEs previously identified by Kirkpatrick and Rushing to describe a campaign of experimentation (COE) for UTACC that will assist in the realization of UxS as a functional system (Larreur, 2016).

Two other projects are in progress concurrently with this thesis. The eighth thesis is narrowing the scope of the MOPs and MOEs developed by Kirkpatrick and Rushing to further identify those MOPs and MOEs specific to the human–machine interface (HMI) in order to determine the appropriate sensor suite necessary for UTACC's information exchange requirements (IERs) (Kulisz & Sharp, 2017). The ninth thesis is identifying the IERs for a limited set of immediate action drills commonly performed by a USMC fire team (Chenoweth & Wilcox, 2017). Due to a paucity of known evaluation methods focused on human–machine teaming, the purpose of the current thesis is to define situation awareness (interchangeably referred to as situational awareness or SA) models, requirements, and methods of evaluation for the UTACC human–machine fire team.

B. NECESSITY OF UTACC SA

As will be reviewed in Chapter II, SA has been and will continue to be critical to decision making in infantry operations (Endsley et al., 2000). Furthermore, the inputs on SA have increased rapidly alongside the evolution of technological advances. Rapid technological developments have created environments where a seemingly endless stream of data is available. Simultaneously, the processing speed of computing machines has maintained a similarly dizzying pace. The challenge is in leveraging the processing of the correct type of data to produce the desired type of information devoid of the unnecessary details. Unlike remotely operated vehicles in which the operator's cognitive focus is on the vehicle or at best the individual task of the vehicle, a specific goal of UTACC is to reduce the cognitive load on the operator by leveraging the collaborative autonomy of the entire team.

Though the components of the UTACC team are separate physical entities, namely individual Marines and a UxS that combine to form a human–robot fire team, the focus of this thesis' analysis of SA is on their collective mission as opposed to merely their individual SA requirements. To illustrate this point, a robot, like a human, has an array of sensors that can provide the necessary information to build the SA of that specific entity. In some cases, a robot's sensors are more limited in their field of view (FOV). In other cases, however, the UxS may be capable of sensing its environment in a way that a human is incapable of (e.g., infrared electromagnetic [EM] energy or other non-visible portions of the EM spectrum). Whereas the human brain automatically "fuses" various sensory inputs (for example, auditory, visual, and tactile), a UxS must be designed and programmed to fuse its various sensor inputs. Though each entity may share certain environmental data while other environmental data is unique to one entity, the collective SA of the fire team as a whole is ultimately the requirement for appropriate decision-making. In other words, individuals have individual data needed to perform their individual taskwork and shape their individual SA. In a team, however, individual taskwork is inevitably interdependent with other teammates' individual taskwork, and the same is true for individual SA.

C. THESIS ORGANIZATION

This thesis is organized into four additional chapters. Chapter II is a literature review that explores the concept of SA and various SA models, Coactive Design methodology, the adaptation of SA into the infantry environment, SA evaluation methods, team SA, and SA evaluation techniques. Chapter III details the research methodology in evaluating various SA models and their use in the infantry environment. Chapter IV presents a UTACC team SA model, an illustrative SA requirements analysis for a common Marine Corps infantry fire team task, and various SA evaluation methods. Chapter V summarizes the results of the thesis and provides recommendations for future research.

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II. LITERATURE REVIEW

A. UTACC CONCEPT OF OPERATIONS

The development of a UTACC CONOPS was the initial step within the research initiative put forth by MCWL (Rice, Keim, & Chhabra, 2015). Their thesis laid the groundwork and formulated a roadmap for follow-on research. Key findings and recommendations of Rice et al., including a threat and vulnerability analysis, the importance of realizing the risk in attempting to achieve some type of fully automated solution, and the necessity of explicit information requirements to support a complementary interface between robots and humans, all formed the basis of subsequent theses. This thesis makes use of their extensive task-oriented analysis for a reconnaissance mission derived from the Marine Corps Planning Process (MCPP) in order to form a basis for modelling UTACC SA.

B. SITUATION AWARENESS

A concrete and quantifiable definition of SA is necessary to build an effective method of evaluation. Multiple researchers have defined SA as either the "process of gaining awareness, the product of gaining awareness, or a combination of the two" (Salmon et al., 2008, p. 299). The initial significant and most widely accepted definition of SA is as a product, or a "state of knowledge," that results from a process of "situation assessment" (Endsley, 1995, p. 36). Endsley used the following definition of SA for her work on measuring SA in military aviators: "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (1995, p. 36). Although this definition of SA is limited to being merely a product, when combined with her definition of situation assessment, Endsley produced a whole concept of SA that accounts for the interdependence between the process and product involved in SA (1995, p. 36).

A contemporary of Endsley defined SA as "the knowledge that results when attention is allocated to a zone of interest at a level of abstraction" (Fracker, 1988, pp. 102–103). From this definition, the “focal region” is “the intersection of zones of interest with levels of abstraction” (Fracker, 1988, pp. 102–103). Fracker’s definition assumed that attention was a limited resource, and that SA was better with a narrowly scoped focal region compared to a broader focal region. Fracker defined the zones of interest in a similar manner as Endsley, but noted that they were not necessarily nested or encapsulated within each other. He defined levels of abstraction as the context of the assessment (Fracker, 1988, p. 103). Understanding of mission context, for example, is different from specific threat context. Different levels of abstraction, unlike zones of interest, were hierarchical. In this way, a pilot who understands mission intent can better understand the impact of a specific threat at a specific time and spatial location (Fracker, 1988, p. 103).

Smith and Hancock defined SA as not only a product or a process, but instead as an interconnected whole concept that could not necessarily be defined by the sum of its parts (Stanton et al., 2013, p. 243). They defined it as an “adaptive, externally directed consciousness.”

> [Smith and Hancock] take consciousness to be that part of an agent’s knowledge-generating behavior that is within the scope of intentional manipulation… [Smith and Hancock] view SA as generating purposeful behavior (behavior directed toward achieving a goal) in a specific task environment. The products of SA are knowledge about and directed action within that environment. [Smith and Hancock] argue that SA is more than performance. More fundamentally, it is the capacity to direct consciousness to generate competent performance given a particular situation as it unfolds. (Smith & Hancock, 1995, p. 138)

Smith and Hancock viewed knowledge about and decisive action in the confines of the environment as the results of SA, a distinctly different view from Endsley and Fracker (Smith & Hancock, 1995, p.138). They argue that SA is not possible without prior experience that developed a certain “level of adaptive capability,” a notion similar to Fracker’s view of schemata (Smith & Hancock, 1995, p. 139). Thus, SA is cognition that drives the behavior that searches the environment for the cues that will enable effective action within the constraints of the task and environment (Smith & Hancock, 1995, p. 141).

Common to all of the preceding definitions of SA are the concepts of a process that generates knowledge from the environment and product, or state of knowledge, which represents a threshold for decision making in order to achieve an explicit goal. The research of both Fracker and Endsley was conducted in a military environment, which is mission-goal oriented in all its tasks. Smith and Hancock's work went a step further and clearly distinguished between SA as a product of external or "environmental" goals versus introspection as a product of internal or "agent" goals (Smith & Hancock, 1995, p. 138). The agent (i.e., a Marine or a robot) must be performing an externally oriented task from which to derive the need for information about the environment that will inform the SA and decision making of the agent. The requirement that SA is task oriented is what limits the necessary information to only that which is pertinent to the task.

Within the context of UTACC, it is important to note how SA applies to the "machine" component of the Marine–machine team. As both agents perform these externally oriented tasks, the robot component will require both environmental information and a goal/mission-based context to analyze, compare, and make decisions just like a Marine.

C. SA MODELS

Multitudes of SA models currently exist and are in extensive use within military and aviation contexts, among others. Most models include some type of process in which environmental data is received, processed, and compared against pre-formulated schemata. Models differ in how they emphasize the importance of SA, as either a process or a product, both of which are tightly coupled to decision making as a whole. This section explores various SA models applicable to UTACC.

1. Fracker's Situation Assessment Model

Fracker viewed the measure of a situation assessment model as one that indicated methods that would improve SA and methods that would not (Fracker, 1988, p. 103). Fracker modeled situation assessment as the intake of environmental data, the comparison of that environmental data with long term memory "schemata," and the application of those schemata to the situation until the agent achieves a level of SA. Here, “schemata” is the term used for knowledge that is stored in long-term memory. He saw the usefulness and application of those schemata as inversely proportional to the level of effort that working memory needed to expend. A brief example is useful for illustrating this key concept.

A veteran pilot with significant stored knowledge is able to rely on minimal environmental data in order to choose the correct schemata to apply to the environment and rapidly build SA with minimal working memory effort. A novice pilot, on the other hand, does not have the experience to conduct pattern matching and so must seek out a greater amount of environmental data in order to build SA using multiple rudimentary schemata (Fracker, 1988, pp. 103–104). The novice must expend more effort and needs more time to define the situation than the veteran, who relies heavily on rapid recognition and pattern matching to achieve the same quality of SA. Figure 1 is a visual depiction of Fracker’s model of situation assessment, as interpreted by the authors.

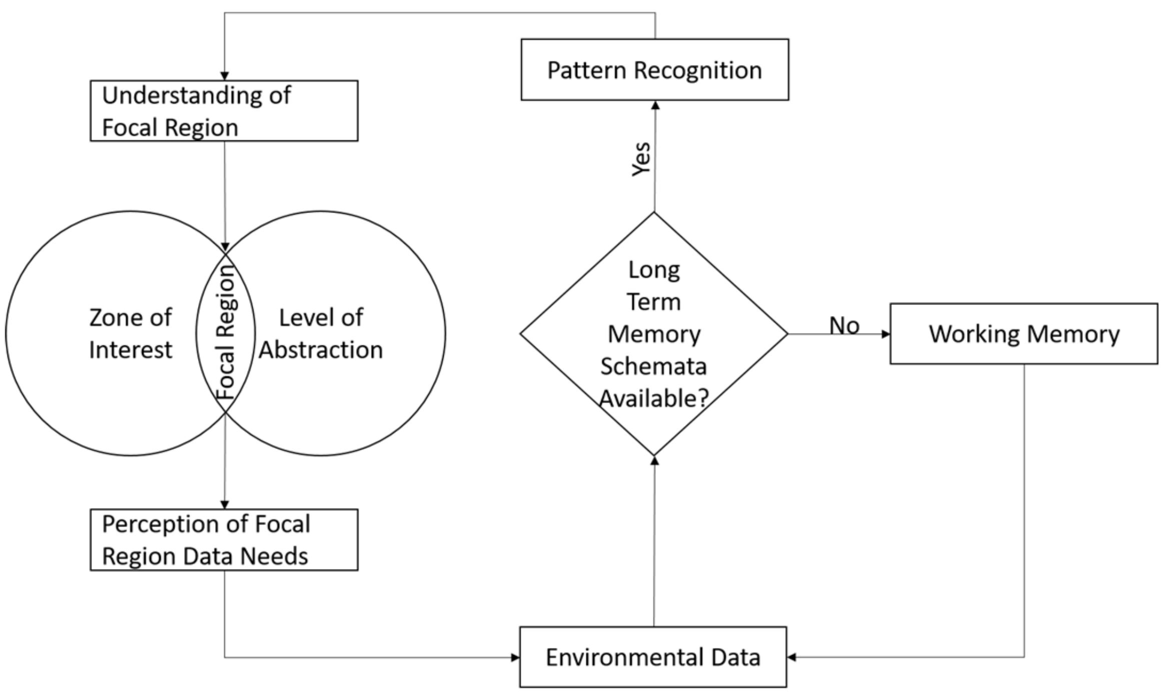


Figure 1. Visual Depiction of Fracker’s 1988 Situation Assessment Model

Fracker’s inverse relationship between working memory load, depth, and quality of schemata is worth highlighting in particular because he viewed attention as a finite resource (Fracker, 1988, p. 102). A novice pilot must expend more attention than a veteran pilot does on non-situational assessment tasks like basic aircraft operation and therefore has less attention available to expend on situation assessment. The novice needs more attention resources than the veteran does in order to conduct situation assessment. A veteran pilot, on the other hand, has more attention resources but needs less in a similar situation. Knowledge and experience are the critical factors that enable rapid situation assessment that can deliver quality SA.

That point will have particular impact on UTACC given its context. Marines typically deal with situations that are at least slightly different from their schemata in some manner, regardless of training and experience. More knowledgeable and experienced Marines typically have more developed schemata available to them and they have experience matching environmental data to their schemata. The training and readiness criteria for Marine Military Occupational Specialties (MOSs) increase in complexity and scope over time and incorporate previous, narrower schemata into those more developed schemata (Department of the Navy: Headquarters United States Marine Corps [DON HQ USMC], 2013, p. 1–2). One of the key tasks of assessing the SA impact within UTACC will be the measurement of the robotic team member’s impact on the attention resources of the fire team. This will facilitate measurement and assessment of interface mediums and methods between the robot and other fire team members.

2. Endsley’s Model of SA

Endsley’s model of SA is depicted in Figure 2. She defined three levels that make up SA: perception, comprehension, and projection (Endsley, 1995, p. 35). Although the levels are hierarchically numbered, Endsley nested the levels within each other in her model because the three levels cannot exist in isolation (Endsley, 1995, p. 35).

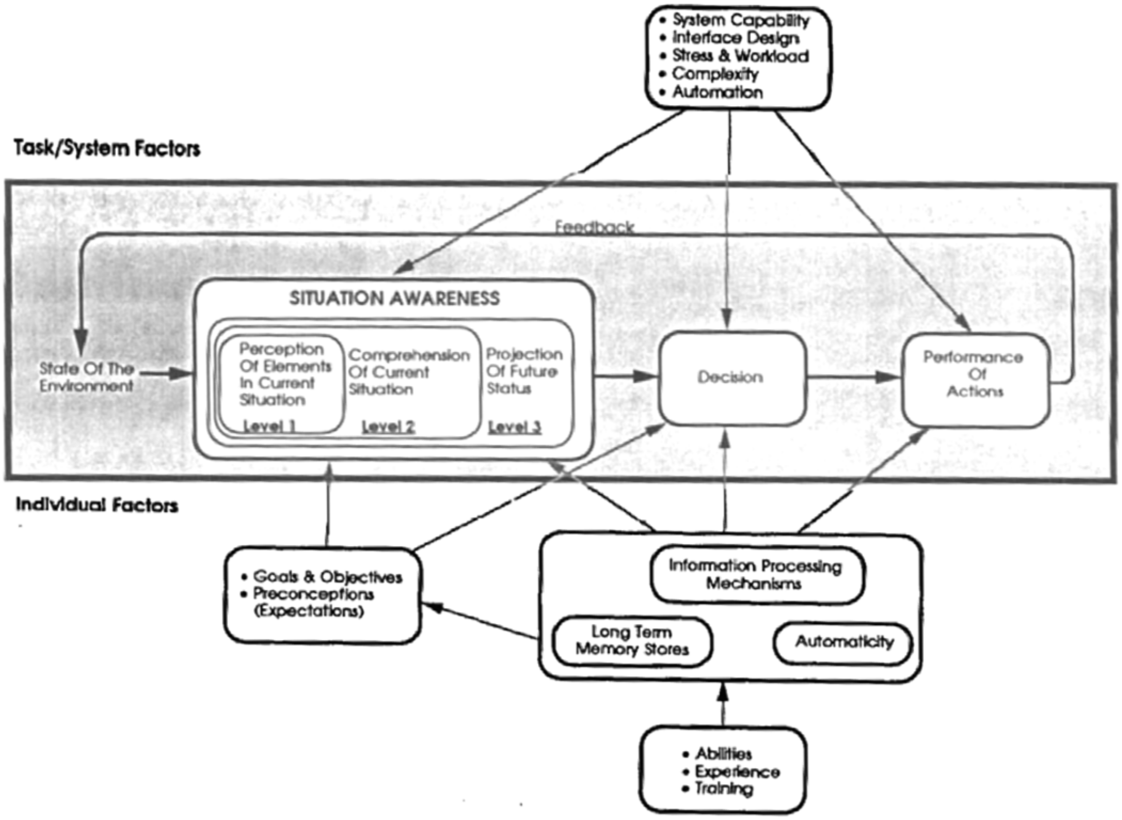


Figure 2. Model of Situation Awareness in Dynamic Decision Making.
Source: Endsley (1995).

Perception requires the agent to gain awareness of pertinent data about relevant objects within the environment in order to comprehend their impact upon the environment, the agent, and the task (Endsley & Jones, 1997, p. 17). Once the agent comprehends the pertinent data within the situation, the agent can project the immediate next actions or the impact of the situation elements on their own next actions (Endsley & Jones, 1997, p. 17). In order to seek out the data necessary to comprehend the situation, however, the agent must project possibilities and probabilities (usually through some form of planning that provides an understanding of the task), comprehend the impact of those possibilities along with the likelihood of the associated probabilities, and then determine a means of seeking out the necessary data. Endsley's three levels of SA are therefore interdependent—an agent cannot achieve Level 1 SA without at least some measure of Levels 2 and 3.

Endsley separated the decision cycle from “task/system factors” and “individual factors” that influence and affect an agent’s performance of the decision cycle (Endsley, 1995). The task/system factors that Endsley derived resulted from the focus of her work on military aviation and the effect of aircraft interaction on pilot SA. This has particular cross-applicability to the UTACC project because of the similarities between the pilot/aircraft interaction and the Marine/UxS interaction. Aside from the distinct difference between roles as operator versus collaborator, the system factors are still a valid construct to account for the impact of the system (UxS) on SA.

3. Smith and Hancock’s Perceptual Model

Smith and Hancock approached their model of SA from a different perspective than both Endsley and Fracker. What Fracker and Endsley called SA, Smith and Hancock defined as knowledge about the environment interpreted through the lens of the external task (Smith & Hancock, 1995, p. 138). What Fracker and Endsley called situation assessment, Smith and Hancock referred to as the behavior generated by SA that acquires task-relevant information from the environment. Situation assessment is the “agent’s solution to the problem of knowing those cues and demands in the environment that enable it to take action that aligns with the dicta of the arbiter of performance” (Smith & Hancock, 1995, p. 141). They used Neisser’s (1976) perception–action cycle as the framework for their model of SA and added what they termed the “invariant,” as shown in Figure 3 (Smith & Hancock, 1995, p. 141).

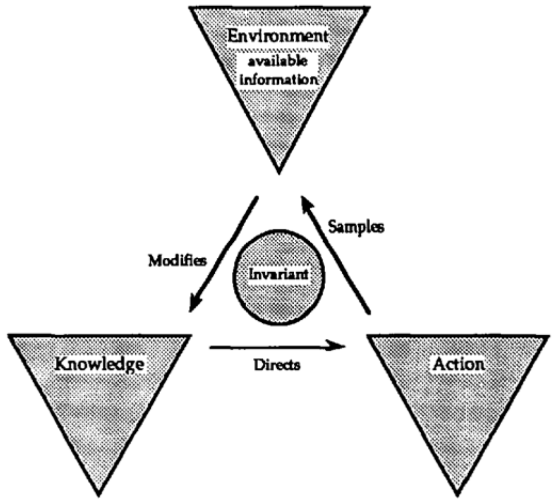


Figure 3. Perceptual Model of SA. Source: Smith & Hancock (1995).

Smith and Hancock focused on the invariant as the driver of their SA model because interaction between the agent and the environment is necessary for SA to exist:

> [The invariant is] the structure of the agent's adaptation to the environment: It forms the linkage among information, knowledge, and action that produces competent behavior. Specifically, the invariant codifies the information that the environment may make available, the knowledge the agent requires to assess that information, and the action the knowledge will direct the agent to take to attain its goals. (Smith & Hancock, 1995, p. 141)

They derived the invariant from their view that SA requires the intersection of the agent and the environment during an externally driven task as depicted in Figure 4 (Smith & Hancock, 1995, p. 138). They used an example of commercial air traffic control (ATC) to make their point.

Experienced air traffic controllers had the requisite self-awareness to recognize either a lack of or loss of knowledge and adapt to it in order to increase their state of knowledge to a level sufficient to execute their task (Smith & Hancock, 1995, p. 142). By defining SA as the driver that depends on the invariant, and not a state of knowledge, they account for the situation where an agent's knowledge is low, but the agent's awareness of his or her current state of knowledge compared to the state of the environment is high. Thus, SA "not only supports the construction of the picture but also guides the assessment of its integrity" (Smith & Hancock, 1995, p. 142). According to their definition, an agent with a low knowledge state could still be said to have good SA if he or she is aware of a lack of knowledge, the impact of that lack on his or her task performance, and the behavioral adaptations necessary to overcome that lack of knowledge.

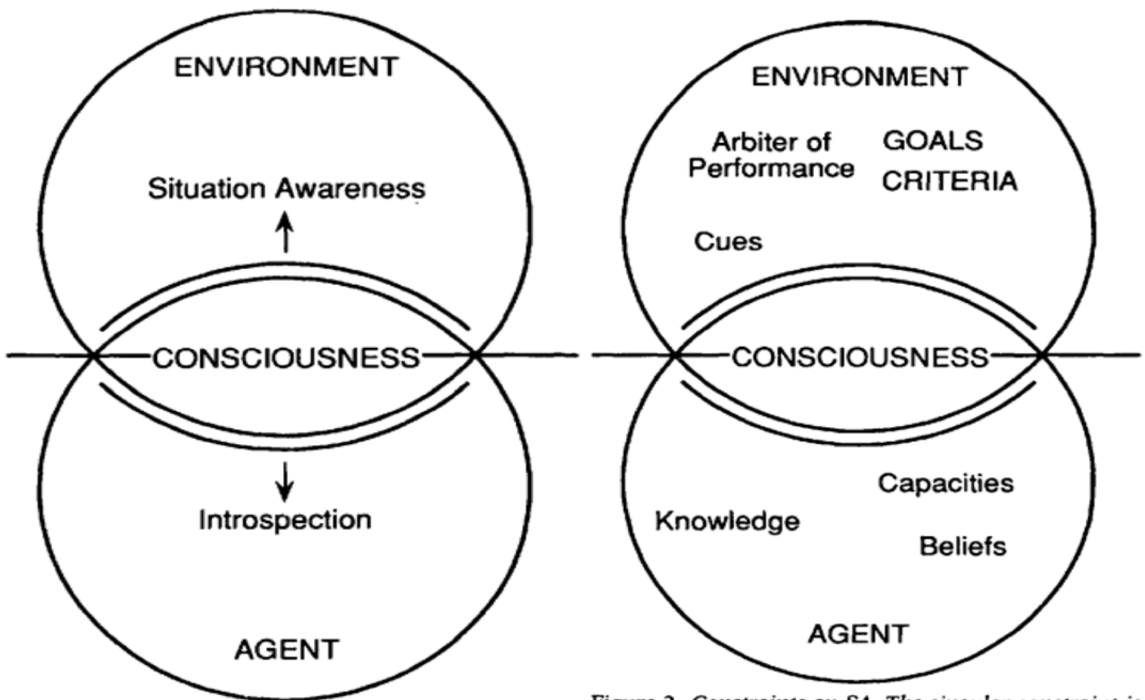


Figure 1. *An approach to defining situation awareness (SA) through explicit recognition of the centrality of externally oriented consciousness. The central (horizontal) line provides an arbitrary distinction between exogenous and endogenous orientations of consciousness and represents a distinction between SA and introspection.*

Figure 2. *Constraints on SA. The singular constraint is the presence of a normative arbiter of performance in the agent's task environment. The arbiter specifies for the agent task-relevant constraints and criteria for performance. Adaptation to the environment requires the agent to adopt the arbiter's specification of constraints and performance variables. Cues and demands are stimuli that unfold in the environment. The agent's internal constraints are those that shape its intentionality.*

Figure 4. Intersection between Environment and Agent within the Consciousness. Adapted from Smith and Hancock (1995).

The UTACC project can benefit from Smith and Hancock's model by using it to design and assess robotic team members on their understanding of mission and task intent. Robots that provide feedback when they need information but are unable to acquire it are more useful than robots who discount information needs that they cannot support. This will drive requirements for the design of sensors to support mission needs instead of limiting mission capabilities based on the situation assessment capabilities of a particular robot's sensor suite. On the other side of that coin, evaluations of robotic team member designs can inform commanders of what mission sets they are capable of supporting when in use.

At a deeper level, the identification of environmental data requirements in order to accomplish a given task is not a trivial undertaking. Most human members of the military require years of training and experience to develop the schemata necessary to accomplish operational missions. Robotic team members that utilize advanced intelligence and machine learning in order to adapt to unknowable situations may require similar time and training to achieve the same level of schemata. The benefit will be that each robot can learn from other robots' experiences, thus shortening the training needs of all similar robots.

Experienced human team members understand the limitations of their different sensors and use a combination of means to gain a picture of the environment. Robotic team members will have to do the same, but they must understand their own limitations, and be able to reason and correlate similarities and differences between input means in order to do so. This will likely be the more difficult task than simply assessing the state of knowledge at any particular time.

D. COACTIVE DESIGN

Coactive Design is a methodology that seeks to design robots that act as interdependent members of a team with humans instead of purely as user-operated tools or fully autonomous vehicles (Johnson, 2014, p. 1). Too little or too much autonomy is not necessarily helpful in a team environment. Infantry forces do not expect or want complete autonomy from other human soldiers; why would they desire it in robotic teammates? Rather, the desire is for the "right" amount of autonomy. Soldiers work closely together to achieve unit goals. As an example, the automatic gunner in a fire team relies on the assistant automatic gunner to carry spare barrels and ammunition, as well as to assist with targeting, reloading, and barrel changing while in a firefight (USMC, 2016, p. 3-50). Coactive Design specifically seeks to build systems that operate in "close and continuous interaction with people" (Johnson, 2014, p. 46). Johnson summarized his key point in regards to finding the right balance:

> Even when self-directedness and self-sufficiency are reliable, matched appropriately to each other, and sufficient for the performance of the robot's individual tasks, human–robot teams engaged in consequential joint activity frequently encounter the potentially debilitating problem of opacity, meaning the inability for team members to maintain sufficient awareness of the state and actions of others to maintain effective team performance. (Johnson, 2014, p. 50)

Johnson built on the previous views of automation in terms of self-directedness and self-sufficiency by adding a third dimension termed "capability to support interdependence" (Johnson, 2014, p. 51). In Figure 5 is a depiction of those definitions as orthogonal dimensions. Johnson presented the need for truly interdependent teams to be capable of both required and opportunistic relationships (Johnson, 2014, p. 62).

As an example, a robotic member of a fire team may see or somehow sense an enemy position. The robot is required to report the enemy position to the fire team leader (required relationship) and provides a grid location. A robot capable of opportunistic relationships might notice that the fire team leader is unable to correlate that grid to the real world and offer to designate the enemy position using other means like a laser or direct fire munitions. Subsequently, the robot may notice that other team members' fires miss the target and provide corrections.

Another scenario might find the team tasked with reaching an objective past a low wall that the humans can climb but the robot cannot surmount. The hard relationship requires the robot to inform its teammates that it cannot climb the wall and must go around. A robot capable of opportunistic relationships may notice materials suitable for a ramp and recommend their use in order to maintain team integrity. If the robot was isolated from its team members or no materials were available, it would simply seek a route around the obstacle. Each of the prior scenarios depend on the robot's awareness of the environment, the mission, the requisite tasks to achieve the mission, the roles of the different team members, and the opportunities for team interdependence to produce results.

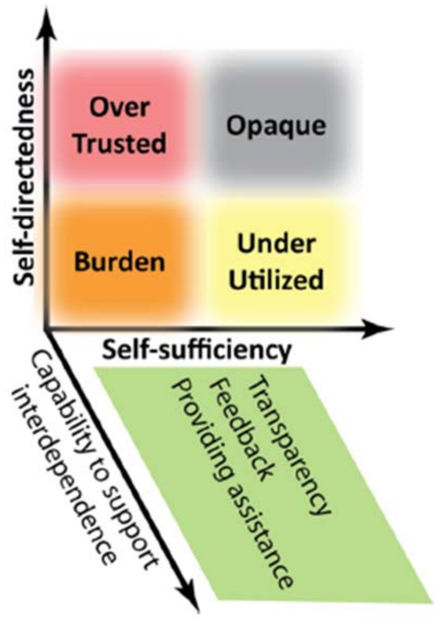


Figure 5. Support for Interdependence as an Orthogonal Dimension to Autonomy and Some Opportunities this Dimension Offers. Source: Johnson (2014).

Observability, predictability, and directability (OPD) are the key components to achieving interdependence within human–robotic teaming (Figure 6). Johnson viewed OPD as the necessary requirements for designing the interface between interdependent humans and robots—the mechanisms that will support SA within the team (Johnson, 2014, p. 67). In some ways, OPD is comparable to Endsley's three levels of SA, but through the lens of a human–robot interface. It is not a perfect fit; Endsley's levels focus on agent interaction with the environment, whereas OPD focus on the internal interaction of team members, which is both driven by and drives the team's interaction with the environment. Since the use of OPD removes opacity between Marine and robot, it appears that employing OPD will be a powerful construct in the design of interfaces that promote team SA. Using the automation dimensions from Figure 5, human infantrymen would fall into the opaque quadrant without the controls that military training and organization impose through communication. Similarly, design considerations should target a robot teammate not in an effort to establish a fully self-sufficient and self-directed UxS, but rather a semi-autonomous and interdependent teammate.

Team accountability and leadership supervision built into the chain of command provide the most basic level of observability, while training and standard operating procedures achieve predictability. Using standardized orders processes with a feedback mechanism in the form of confirmation of orders receipt achieves directability. Additionally, directability can also be achieved through the implementation of commander's intent. Confirmation that the intent of the orders was understood can then achieved through supervision (observability) of the directed action. When dealing with direct human interaction, procedures are designed to maximize the interfaces that are available in the form of the five senses (primarily visual, aural, and tactile), given the environmental constraints. The use of technology allows for the interface itself to be designed to best support the preferred procedures of Marines.

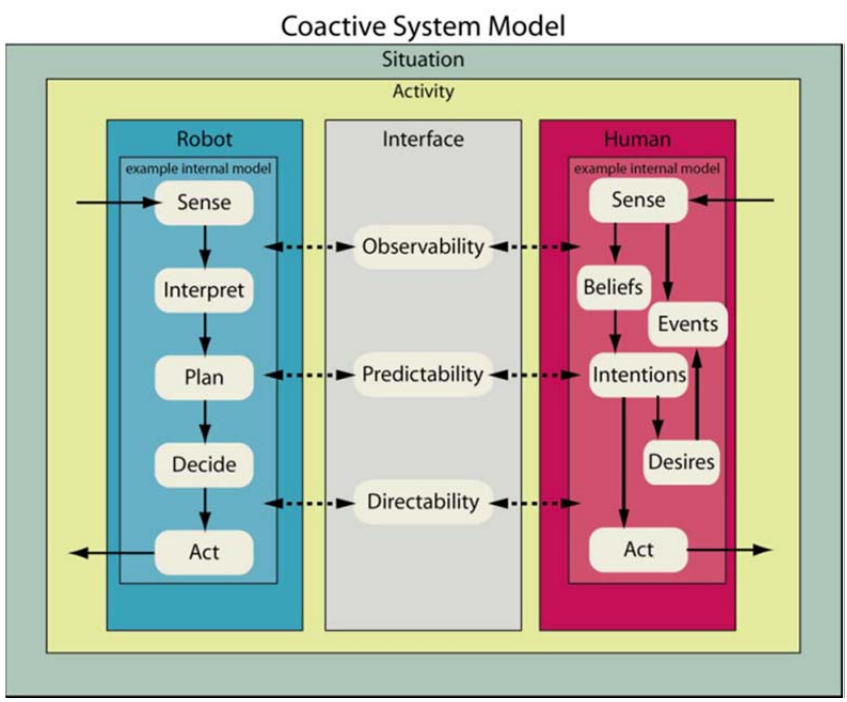


Figure 6. Coactive System Model Based on OPD.
Source: Johnson (2014).

The design of UTACC robots must be guided by the principle that the interface support human infantry operations. Consider the following scenario: A robot detects hostile fire directed toward its fire team, slews its camera to the threat direction, identifies the threat, takes a picture, uses a laser–rangefinder to determine the threat location, and then transmits grid coordinates and imagery of the threat to the fire team leader's SA tablet. While the fire team leader looks down to read the alert on his or her tablet, action is delayed and SA is lost. Even if the human team members realize they are under fire, they may need to wait for the fire team leader to interpret the tablet information before they know the threat location. Conversely, a different robot does the same initial targeting, but then uses machine speech to inform the fire team of the threat direction and immediately returns fire. The human members of the team are immediately cued, and they also return fire.

Both methods provide the same SA information: threat presence and location. The second method however, is more useful. It takes into account the specifics of the situation and selects the optimum interface to transmit the minimum information required to build the team's SA. The first robot may meet the same requirements, but the second robot was designed with the human–robot teaming interface in mind. In this fashion, UTACC can use OPD to ensure robots are designed around the ability to conduct Marine infantry missions and the ability to interface effectively and appropriately with the human members of a fire team.

E. USMC INFANTRY MISSIONS

USMC infantry battalions have four mission essential tasks (METs): conduct amphibious operations, conduct offensive operations, conduct defensive operations, and conduct stability operations (DON HQ USMC, 2013, p. 2-2). METs are derived from the Marine Corps Task List (MCTL) and are the measures used to assess and report readiness of Marine Corps organizations. METs are further broken down into training and readiness (T&R) events that units train to and are evaluated on as a means of determining MET proficiency. Those T&R events extend all the way down to the level of individual Marines. The battalion, company, platoon, squad, fire team, and individual training events are displayed in Appendix A. The following sections explain the relevance.

F. SITUATION AWARENESS IN THE INFANTRY OPERATIONAL ENVIRONMENT

In 2000, Endsley et al. expanded their 1995 model of individual SA and her 1997 model of team SA as part of the United States Army Research Institute Infantry Forces Research Unit's Situation Awareness Project in order to improve techniques and tools used by the Army's infantry forces to enhance their SA (Endsley et al., 2000, p. 33). Their problem statement addresses many of the SA-related concerns within UTACC:

> Information-age technologies and emerging organizational structures are guaranteed to impose new information processing and decision making challenges on Infantry soldiers and leaders. A key question revolves around how to manage abundant real-time battlefield information in such a way that improves the Infantryman's SA. How much of the information processing challenge can be handled by proper training? How can SA-focused training programs be optimized to meet Infantry requirements? *How can we measure SA performance so that we know whether new training programs and advanced systems are part of the "solution"? How do we know which new technologies truly contribute to better SA for Infantry leaders and soldiers at various echelons? Which information technologies provide sufficient value to make it worth changing the soldier's physical load or the unit's mission load? What level of distraction from direct observation of the battlefield is acceptable to harness the benefits of using SA equipment? How do new organizational and operational concepts impact critical SA parameters and decision making processes?* (emphasis added) (Endsley et al., 2000, p. 5)

Endsley et al. determined that key infantry SA inputs could be defined using the Mission, Enemy, Troops, Terrain, Time, Civil (METT-TC) structure already used by infantry forces to build a basic picture of the situation (Endsley et al., 2000, p. 18). Given the UTACC project's goal of developing robotic partners for integration at the fire team level, the authors concur that this is an appropriate guide to basic mission SA in the infantry environment. Examples of METT-TC needs of infantry units from the battalion-level down to the individual soldier across the phases of operations are depicted in Table 1, which was first published in Endsley et al. (2000).

Table 1. Summary of Representative Situation Elements for Infantry SA. Source: Endsley et al., (2000).

	Phases of Infantry Operations				
Echelon	***Staging***	***Deploying***	***Pre-Operations***	***During Operations***	***Post-Operations***
Brigade	• Mission, enemy, area of operations (AO) • Weather • Status of battalions (Bns), brigade (Bde) staff • Division's concept for deployment, operations • Task organization changes • Strengths/limitations of assigned units and leaders • Time remaining before first movement • Time required to fully deploy the Bde • Time when Bde must/can assume control in AO	• Location/status of subordinate Bns, companies (COs) • Tactical developments in AO • Enemy actions and condition • Capabilities, limitations and past experience of US/friendly Bdes • Changes to division plan • Changes to division order or concept • Status and availability of support units • Condition of forward assembly areas	• Changes to availability/condition of routes • Changes affecting air movement or C4I • Status of division and adjacent Bde formations, movements • Vulnerability to enemy action • Changes at the line of contact • Changes to time of commitment • Availability and condition of attached or supporting forces	• Location/condition of assigned forces • Location/activities of enemy units in area of interest • Changes to air situation • Location/progress of adjacent, reserve Bdes • Division appreciation of situation • Combat support (CS) or combat service support (CSS) constraints • Conditions that trigger changes to plan • Location of command posts (CPs) and key leaders	• Time until next mission • Nature of next mission • Condition, location and status of assigned forces • Enemy location, condition, and activities • Time until resupply or reorganization complete • Need to replace leaders • Status of morale and key systems • Changes to task organization • Battle damage to AO that affects future operations
Battalion	• Mission, enemy, AO • Weather • Status of COs, staff, and special platoons • Bde movement plan • Time available to prepare and train • Special requirements for advance parties/debarkation details, time to provide them	• Location and status of COs, other Bns • Changes to enemy situation • Changes to friendly position in theater • Availability of transportation and supply at destination • Changes to Bde or division plans • Changes to deployment of attachments or supporting units	• Conditions of routes or avenues of approach • Status and coherence of Bde formation • Location of enemy forces • Susceptibility to enemy fire or air attack • Imminence of commitment • Exact location of passage points or lanes • Location of obstacles and defenses around them	• Location/conditions of COs, platoons • Location/status of other Bns • Enemy location, activities • Condition of C4I links/sites • Activities of Bde's supporting FA and engineers • Changes to terrain that affect operations • Location of hazards in sector or zone • Location/status of trains and CPs • Location of key leaders	• Time until next mission • Nature of next mission • Location/status of COs, other Bns • Enemy location, activities • Time until refitting/resupply complete • Need to replace leaders • Morale/energy of Bn • Status of key systems • Changes to Bde's allocation of CS • Condition of CS, CSS units
Company	• Mission, enemy, terrain • Time to move • Availability and condition of assigned soldiers and leaders • Location and nature of transportation • Special staging, movement and equipment requirements • Soldier training and morale readiness	• Changes to the situation • Changes to orders or organization • Destination weather • Location of CO supply trains • Enemy location/activities • Status of attachments • Location of key Bn leaders • Sequence of unit arrivals	• Changes to orders or to battlefield conditions • Conditions at destination • Timing of commitment to action • Location and status of other COs • Access to supporting fires and engineers	• Location and condition of platoons and squads • Location and situation of other COs • Enemy location, activity, and condition • Enemy use of air, artillery, nuclear/biological/chemical (NBC) • Location of obstacles/hazards • Conditions limiting use of wpns • Time left to accomplish mission	• Time until next mission • Disposition of Bn/Bde • Strength of personnel, equipment • Time needed to resupply • Location/activities of adjacent COs • Enemy location/activities • Availability of artillery and engineer support
Platoon, Squad	• Mission, enemy, terrain • Time until departure • Availability and condition of assigned soldiers • Condition of equipment and supplies • Determination of equipment to move separately • Soldier readiness • Individual training needs and opportunities	• Changes to the situation • Unit destination and first mission • Ammunition and supply status • Communications status • Sources of supply • Location and arrival times of other squads and platoons	• Objective • Conditions at the objective • Location of subordinate elements • Location of other squads and platoons	• Location of all unit members and attachments • Losses and their medical needs • Enemy strength and location • Status of/ access to heavy weapons support • Strength and disposition of next two higher levels of command • Loss of leaders	• Time/nature of next action • Disposition of next level of command • Location of adjacent and supporting teams • Supply status, time of resupply • Enemy location and activities • Availability of mortar support • Access to/arrival of special support (NBC decon, etc.)
Soldier	• General situation (mission, enemy, terrain) • Time until deployment • Technical and tactical knowledge deficiencies • Environmental conditions	• Changes to the situation • Exact destination and conditions there • Initial tasks • Imminence of combat • Adequacy of weapons, supplies, medical support	• Destination and conditions there • Location of teammates and other friendly units • Status of critical supplies • Location of enemy	• Orientation • Location of teammates and objective • Specific enemy locations including major wpns • Presence/status of support units • Availability of ammunition and medical support • Location of squad leader • Location and status of hazards	• Time/nature of next action • Location of teammates, other friendly units • Location of enemy • Location of squad and platoon leaders • Adequacy of critical supplies • Safety/condition of unit members

Endsley et al. (2000) highlighted two particular challenges faced by the infantry environment. The first is that the challenge of building and maintaining a cohesive picture of the battlefield via reported observations from the 150 soldiers in a rifle company is exceptionally difficult. Additionally, the relative youth and inexperience of infantry soldiers can add another level of difficulty compared to most other combat arms when attempting to build SA (Endsley et al., 2000, p. 15). UTACC envisions robotic teammates embedded at the very youngest levels of Marine infantry in which a corporal, typically in his early 20s, leads a fire team of three other Marines. UTACC should aim to provide a product that can most seamlessly insert itself into the Marine infantry fire team, but changes to organizational structure or training requirements may be required in order to fully prepare Marine infantry forces to best utilize these new tools.

The infantry-focused model of individual SA, devised by Endsley et al., (2000), is shown in Figure 7. It does not differ significantly in concept from her 1995 model with the exception of using infantry-specific terms and expanding the level of detail used to describe the factors that affect the situation assessment process. The details of the infantry environment are important, however, as they scope the necessary inputs that a UTACC robot would seek out from the environment when executing the externally driven tasks within the infantry mission set. They also frame the environmental inputs in a language that is instantly communicable to the human members of the fire team.

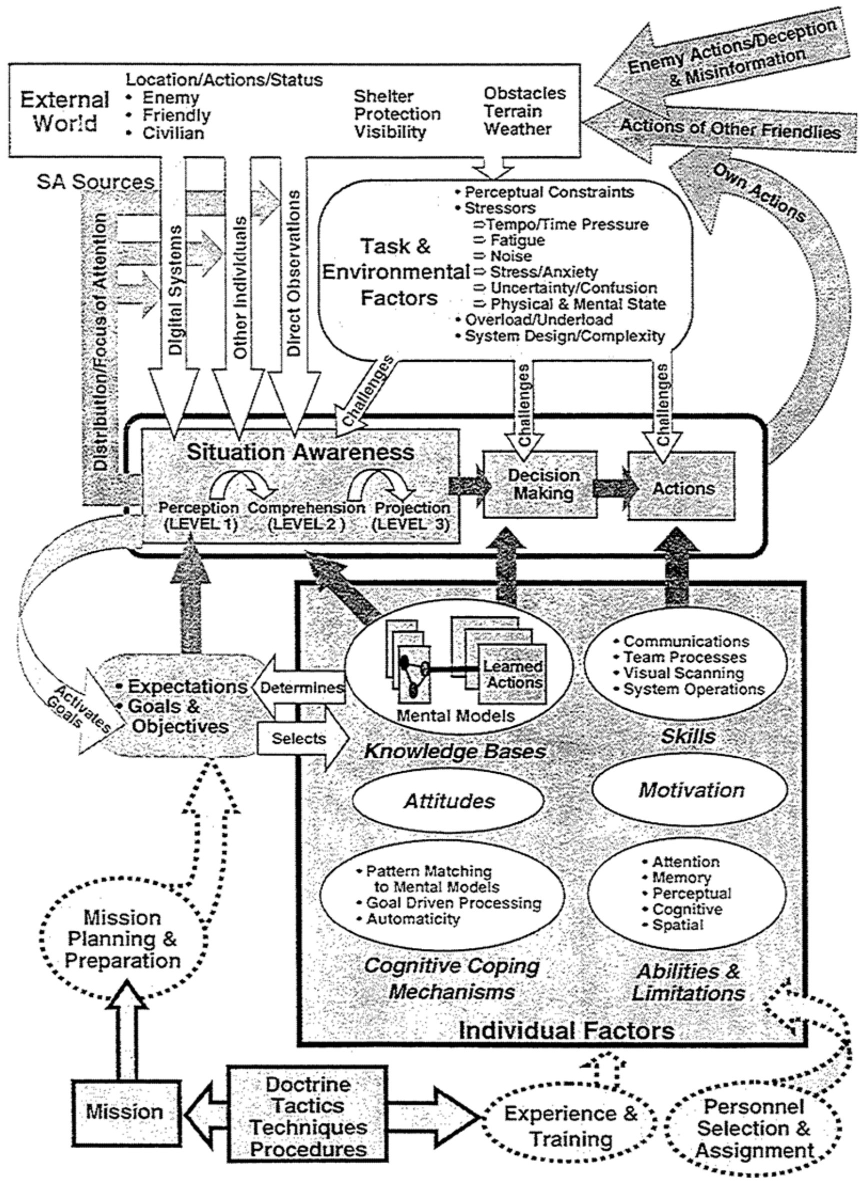


Figure 7. Infantry Focused Model of Individual SA.
Source: Endsley et al., (2000).

G. TEAM SA

Swezey and Salas (1992, p. 4) defined a team as “a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objectives/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership.” The adverbs Swezey and Salas used to describe the interactions between team members are key to the goal of UTACC; their inference is that the people involved in the team are capable of collaboration. A common set of knowledge and a common language are necessary for effective performance of team goals in a dynamic environment. Klein et al. (2005) defined this broad concept as “common ground,” while Cannon–Bowers, Salas, and Converse (1993) called specific sets of common knowledge “shared mental models.” The Marine Corps’ training process is built on that foundation. “Unit and individual readiness are directly related. Individual training and the mastery of individual core skills serve as the building blocks for unit combat readiness” (DON HQ USMC, 2013, p. 1–2). While each team SA model is slightly different, each generally are comprised of three elements: individual SA, teamwork mechanisms (devices, procedures, mediums, behaviors, etc.), and common ground/shared mental models. Comparisons of prevalent team SA models and associated evaluation methods are depicted in Tables 2 and 3.

Table 2. Team SA Theory Comparison Table. Source: Salmon et al. (2008).

Theory	Domain of Origin	Domain Applications	Theoretical Underpinning	Process	Composition	Novelty
Team SA Model (e.g. Endsley & Robertson, 2000)	Aviation	Military, Aviation Maintenance	Three Level SA Model (Endsley, 1995a)	Perception of elements Comprehension of meaning Projection of future states Sharing of mental models	Individual SA Shared SA (Overlapping SA Requirements)	Team SA and Shared SA
Inter and Intra Team SA Model (Endsley & Jones, 2001)	Military	Military	Three Level SA Model (Endsley, 1995a)	Perception of elements Comprehension of meaning Projection of future states Sharing of mental models	Individual Sa Shared SA Inter Team SA Intra Team SA	Inter & Intra Team SA
Team SA Model (Salas et al, 1995)	Generic	None	Three Level SA Model (Endsley, 1995a) Teamwork Theory	Perception of elements Comprehension of meaning Projection of future states Team Processes	Individual SA Team Processes Information Seeking Information Processing Information Sharing	Team SA Processes
Team SA Model (Wellens, 1993)	Military	Military	Three Level SA Model (Endsley, 1995a) Distributed Decision Making Model (Wellens & Ergener, 1988)	Collection of raw data Application of decision rules Selection of plans Information space Situation Space Action Space	Information space Situation Space Action Space Communication Bridge	Distributed Decision Making Model
Distributed Cognition Approach (Artman & Garbis, 1998)	Teleoperations	Teleoperations	Distributed Cognition Theory (Hutchins, 1995)	Shared & Distributed Models	Partly Shared and Partly Distributed Model of Situation	Distributed Cognition Approach
Mutual Awareness Team SA Model (Shu & Furuta, 2005)	Process Control Artificial Intelligence	Process Control (DURESS)	Three Level SA Model (Endsley, 1995a) Shared Co-operative Activity Theory (Bratman, 1992)	Individual SA Mutual Awareness	Endsley’s three levels Individual SA Mutual Awareness	Mutual Awareness Description of SA using heuristic rules
Distributed Situation Awareness Model (Stanton et al, 2006)	Maritime	Military, Maritime, Energy Distribution, Aviation, Air Traffic Control, Emergency Services, Driving	Distributed Cognition Theory (Hutchins, 1995) Distributed SA Theory (Artman & Garbis, 1998)	Individual SA Sharing of Knowledge Elements Team Processes	System Level Emergent Property Activated Knowledge Shared Knowledge	SA as an emergent property of collaborative systems

Table 3. Team SA Evaluation Comparison Table.
Source: Salmon et al. (2008).

Measure	Process or Product?	Citation	Main Strengths	Main Weaknesses
SAGAT (Endsley, 1995b) SA Requirements Analysis (Endsley, 1993)	Product	7	1. Extension of the popular and widely applied three-level model - sound theoretical underpinning and lots of supporting literature 2. Widely applied in a variety of domains 3. Comes with prescribed SA measurement approach (SAGAT)	1. More of a simplistic extension of the individual three level model than a team model in its own right 2. Measurement is complex and impractical for real-world distributed tasks
SAGAT (Endsley, 1995b) SA Requirements Analysis (Endsley, 1993)	Product	5	1. Extension of the popular and widely applied three-level model - sound theoretical underpinning and lots of supporting literature 2. Considers Inter and Intra team SA 3. Comes with prescribed SA measurement approach (SAGAT)	1. More of a simplistic extension of the individual three level model than a team model in its own right 2. Measurement is complex and impractical for real-world distributed tasks
Individual SA Team Processes Compatibility of mental models TARGETS (Fowlkes et al, 1992)	Process & Product	10	1. Provides an insight into the team processes linked to team SA 2. Based on a review of teamwork literature 3. Relates model to team training and speculates on what to measure and how to measure it during team SA assessments	1. Measurement approach is more suited to assessing team behaviour and performance than SA and team SA measurement applications are scarce 2. The model is based on a review of the team literature rather than naturalistic or empirical study 3. Focussed more on team processes than on team SA
CITIES (Wellens, 1993) Post Task Questionnaire Task Performance	Process & Product	4	1. CITIES experimental paradigm developed specifically for assessing team SA 2. Discussion of effects of different communications media on team SA 3. Based on model of distributed decision making	1. SA assessments restricted to CITIES VR environment 2. Limited applications
Observation/Field Study	Process & Product	11	1. Systems level description that permits both individual, collaborative and systemic SA assessments 2. Sound theoretical underpinning	1. Limited applications 2. No prescribed measurement approach 3. Does not describe individual SA processes
TSA Simulation	Process & Product	1	1. Model attempts to describe the content of team SA and the behaviours involved in its development 2. Attempts to describe Team SA through the use of heuristic rules 3. Builds on existing SA theory and uses additional shared co-operative activity theory to present arguement	1. Complex description of team SA 2. Measurement approach is limited to authors domain 3. Limited application or validation
Propositional Networks (Stanton, Salmon, Walker, Baber & Jenkins, 2005)	Process & Product	1	1. Systems level description that permits both individual, collaborative and systemic SA assessments 2. Sound theoretical underpinning 3. Has been applied in a variety of collaborative domains	1. DSA description and measurement is subjective and often occurs post-task 2. Propositional Networks methodology lacks validation 3. Does not describe individual SA processes

1. Endsley's Team and Shared SA model

Endsley defined SA within team settings in two parts. Team SA comprised "the degree to which every team member possesses the SA required for his or her responsibilities" (Endsley, 1995, p. 39). Shared SA, on the other hand, was "the degree to which team members have the same SA on shared SA requirements" (Endsley & Jones, 1997, p. 47). Endsley's view of team and shared SA is depicted in Figure 8.

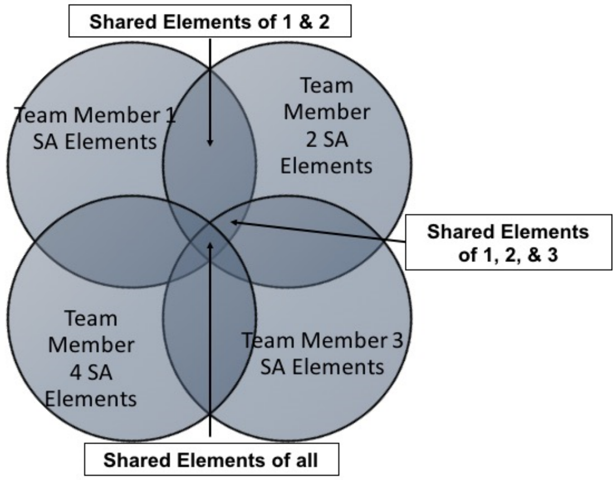


Figure 8. Team and Shared SA. Adapted from Endsley (1995).

2. Salas, Prince, Baker, and Shrestha's Framework for Team SA

Salas, Prince, Baker, and Shrestha (1995, p. 125) hit the nail on the head when they stated the main problem with defining team SA: "Team SA, however, represents far more complexity than does simply combining the SA of individual team members and requires study in its own right." They concluded that team SA was comprised of two interrelated elements: individual SA and team mechanisms (Salas et al., 1995, p. 129). Their framework for team SA is depicted in Figure 9.

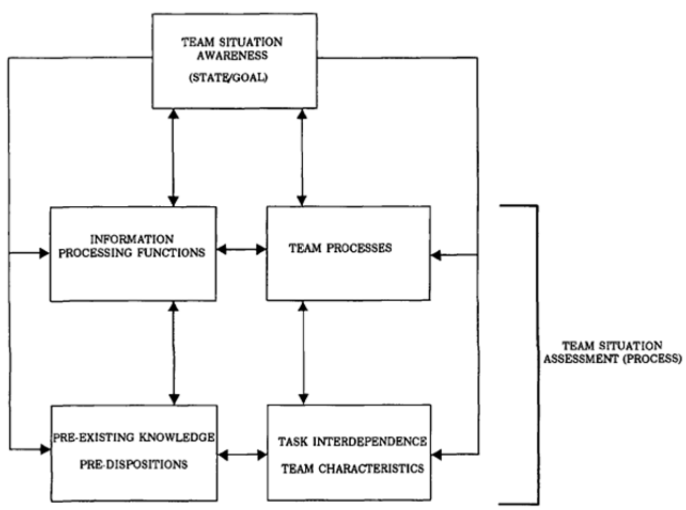


Figure 9. Conceptualization of Team Situation Awareness.
Source: Salas et al. (1995).

Salas et al. (1995, p. 131) believed the situation was the foundation of team SA understanding and measurement because it determined member task allocations which then determine specific team SA requirements. They also viewed the SA requirements overlap that Endsley termed shared SA as a dynamic construct that changed according to the unfolding situation and individual member's SA input needs (Salas et al., 1995, p. 131).

3. Sulistyawati, Chui, and Wickens' Team SA Elements

Sulistyawati, Chui, and Wickens (2008, p. 463) defined team SA in two parts: cognizance of both "system/task status" and "team status." They attributed the need for shared SA between team members to the level of homogeneity between member roles (Sulistyawati et al., 2008, p. 463). The level or degree of interdependency within a team was defined by the need for SA exchanges between members (Sulistyawati et al., 2008, p. 463). The two halves of team SA depicted in Figure 10 are broken down into four elements that together make up system/task and team status awareness. Teamwork mechanisms make up the fifth element: they are the bridge between individual SA and team SA.

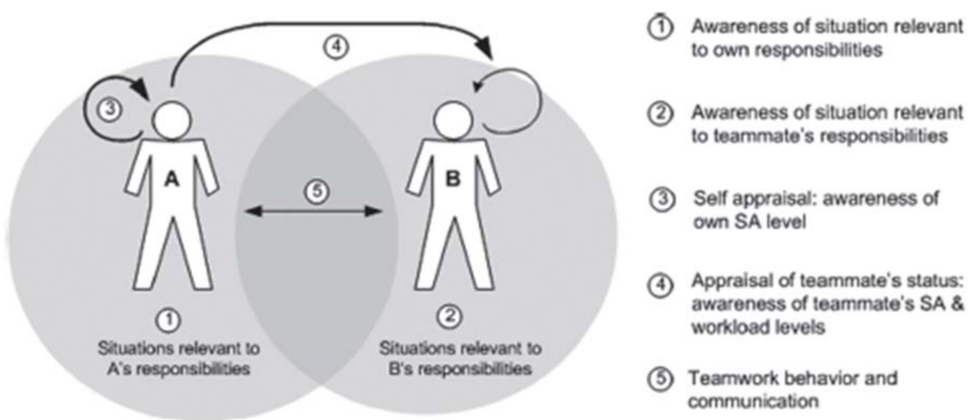


Figure 10. Aspects of Team SA. Source: Sulistyawati, Wickens, and Chui (2009).

H. SA EVALUATION

SA measurement techniques break into seven general categories: "SA requirements analysis, freeze probe recall methods, real-time probe methods, post-trial subjective rating methods, observer rating methods, process indices, and team SA measures" (Stanton et al., 2013, p. 245). The initial step of measuring SA is to conduct a requirements assessment in order to define the measures of performance and effectiveness that will be used (Stanton et al., 2013, p. 245). Several researchers have worked with Endsley to define infantry requirements assessment. The most relevant to UTACC is from Matthews and Strater in 2004 when they developed SA requirements within the METT-TC construct for the infantry platoon commander during Military Operations in Urban Terrain (MOUT). These SA requirements are displayed in Appendix B. The SA requirements were built from a table of primary goals that broke down the MOUT mission set into a table of mission goals and sub-goals (Figure 11).

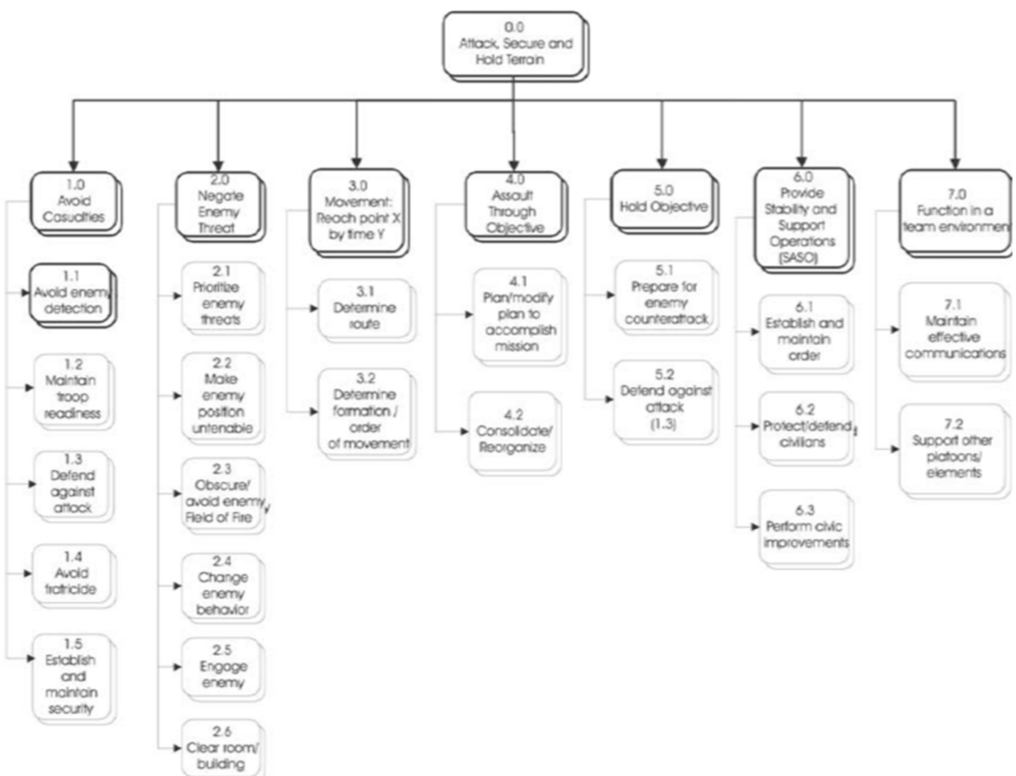


Figure 11. MOUT SA Requirements: Primary Goal Structure.
Source: Matthews, Strater, and Endsley (2004).

Once the requirements are defined, the various methods of measurement can be used based on the unique needs of the evaluation. A compilation and comparison of the most prevalent means that have been used to assess SA are depicted in Table 4.

Table 4. SA Assessment Methods Summary Table.
Source: Stanton et al. (2013).

Method	Type of method	Domain	Training time	Application time	Related methods	Tools needed	Validation studies	Advantages	Disadvantages
SAGAT.	Freeze online probe technique.	Aviation (military).	Low.	Med.	SACRI. SALSA.	Simulator, computer.	Yes.	1) Widely used in a number of domains. 2) Subject to numerous validation studies. 3) Removes problems associated with collecting SA data post-trial.	1) Requires expensive simulators. 2) Intrusive to primary task. 3) Substantial work is required to develop appropriate queries.
Propositional networks.	Modelling technique.	Generic.	Low.	High.	Semantic networks. Concept maps.	Pen and paper.	No.	1) Explores DSA. 2) Explores SA at multiple systemic levels. 3) Considers mapping between elements of information.	1) Can be time-consuming and laborious. 2) Can become unwieldy for complex systems. 3) More focused on SA modelling than measurement.
SART.	Self-rating technique.	Aviation (military).	Low.	Low.	CARS. MARS. SARS.	Pen and paper.	Yes.	1) Quick and easy to administer. Also low cost. 2) Generic – can be used in other domains. 3) Widely used in a number of domains.	1) Correlation between performance and reported SA. 2) Participants are not aware of their low SA. 3) Construct validity is questionable.
SA-SWORD.	Paired comparison technique.	Aviation.	Low.	Low.	SWORD. Pro-SWORD.	Pen and paper.	Yes.	1) Easy to learn and use. Also low cost. 2) Generic – can be used in other domains. 3) Useful when comparing two designs.	1) Post-trial administration – correlation with performance, forgetting, etc. 2) Limited use and validation evidence. 3) Does not provide a measure of SA.
SPAM.	Real-time probe technique.	ATC.	High.	Low.	SASHA_L	Simulator, computer, telephone.	Yes.	1) No freeze required.	1) Low construct validity. 2) Limited use and validation. 3) Participants may be unable to verbalise spatial representations.
SA requirements analysis.	N/A	Aviation, generic.	High.	High.	Interview. Task analysis. Obs. Quest.	Pen and paper, recording equipment.	No.	1) Specifies the elements that comprise SA in the task environment under analysis. 2) Can be used to generate SA queries/probes. 3) Has been used extensively in a number of domains.	1) A huge amount of resources are required. 2) Analysts may require training in a number of different HF techniques, such as interviews, task analysis and observations.

1. Freeze Methods

Freeze methods can be particularly useful for assessing knowledge states by halting scenarios at specific or random points throughout, but that is difficult to do effectively in the infantry training environment. Endsley’s SAGAT method is commonly used in assessing SA in military aviation simulations (Stanton et al., 2013, p. 253). The method was usable because simulators can be paused and all inputs to pilot SA can be zeroed out while questionnaires are conducted. Military aviation simulator networks are large enough to execute relatively large-scale exercises in a realistic environment and the operator interfaces are near-perfect matches for the real thing. SA inputs and agent responses are effectively the same in a simulator and real operations. Endsley evaluated sets of two friendly pilots flying together against five live adversaries—a realistic air combat scenario (Endsley, 1988, p. 794).

It is much more difficult to simulate the infantry environment through computer simulation, especially on a large scale. Infantry forces use live exercise because no computer simulator can effectively recreate the physical realities of a heavily burdened infantryman tackling terrain obstacles during a heavy firefight while trying to maintain SA. Although the freeze method would be very useful in the infantry environment, especially to evaluate SA at critical decision points, the exercise control required to effectively freeze and isolate all participants in a live exercise is significant. Endsley noted that simulator screens and instrumentation had to be zeroed out during freezes or pilots would instinctively look toward the applicable input when questioned, biasing their answers (Endsley, 1988, p. 794). Pilots in simulators can be isolated from their SA inputs during freezes because every input is filtered through the aircraft systems. It is much more difficult to isolate infantrymen from their own senses during a freeze. While the freeze method poses significant challenges in the infantry environment, it is an extremely useful tool for assessing SA throughout the course of an exercise. In particular, it allows for snapshots of SA perception versus reality that can be used as individual comparisons or to study trends over the course of an exercise. Furthermore, a robot has no intrinsic desire to "cheat" or hide its SA at any given time.

2. Non-intrusive Methods

Non-intrusive methods would allow for the most ideal free-play during SA assessments. During freezes, participants have the opportunity to think about the situation and courses of action, and adjust their arbiter or schemata, depending on what model is used. This is an artificiality that would not exist in the real world that could provide participants with the advantage of thinking space, which is a premium on the battlefield. Conversely, it could interrupt situation assessment cycles and disrupt unit synchronicity at key moments and adversely affect subsequent performance. Non-intrusive methods could avoid these problems, but they have limitations as well.

Non-intrusive methods often require significantly more instrumentation than freeze methods in order to analyze SA and information flows, adding costs and evaluation complexity. Furthermore, it is extremely difficult to instrument the human consciousness (or unconsciousness) in order to assess the mental picture—which is the basis of SA. Military instructors and evaluators commonly make notes throughout training evolutions in order to preserve data for later debrief when attempting to be non-intrusive, but there are limitations. There is limited time to attempt to capture a picture of the situation and note the actions of the agent, and instructors cannot know what the agent is thinking during that time. They can assume, but ultimately they have to hope that the agent is later able to recall their thoughts in order to complete the picture of SA perception versus reality.

Nonetheless, utilizing non-intrusive methods to the maximum extent practical would be ideal, especially when dealing with networked infantry and human–robot collaboration. Evaluators would be able to use the data captured to determine if personnel should have had access to SA information when they did not, where the breakdown occurred, and why it occurred.

3. Post-Mission Reviews

Post-mission reviews allow for the scenario to be reviewed in total, a valuable method for putting SA assessments in context. Without data collected from instrumentation, however, the reviews are limited. They will only provide a recall of perception but not a comparison against ground truth.

After-action reviews are a common military tool that are typically used to debrief and learn from training exercises because they are a simple and cost-effective method. They rely on the method of data that was collected throughout the evolution, the integrity of that data, and the recall capabilities of the agents being evaluated. Training or assessment evolutions meant to test SA will involve significant mental workload—relying on the ability of agents who were acting and not solely focused on recording their thoughts to recall their thoughts during precise moments. This is inherently risky. Primacy and recency can significantly affect what events the agents recall. With sufficient instrumentation capable of displaying the true situation, after-action reviews can provide an extremely valuable comparison between the truth and perceived SA as long as perceived SA is extracted before true data can bias the agents. The fundamental weakness of after-action reviews is that they are based on recall, which may not be accurate.

4. Self-Rating Methods

Self-rating methods rely on subjective assessments by the agents themselves. This method can be particularly useful for rating perceptions of agent's own SA and could have significant usefulness in a team SA evaluation environment where team members are being asked for their perceptions of other member's SA.

The main problem with self-rating methods is that agents with low SA are unlikely to know that they do, in fact, have low SA. This should not be confused with just a low knowledge state. An experienced agent who lacks specific information but knows the necessary environmental inputs and behaviors needed to seek them out provides a much more accurate self-rating of SA compared to a novice who is blissfully unaware of critical factors. For UTACC purposes, this could be a very useful metric in evaluating a robot's capabilities: does it understand what it knows and more importantly what it does not know and how that impacts the mission, and is it capable of communicating what it does not know to other team members?

I. TEAM SA EVALUATION

Salas et al. recommended that team SA assessments measure individual SA, team processes, and shared mental models (1995, p. 132). These components can then be analyzed and compared across team members and other teams to identify failures in individuals or the procedures and technology that facilitate team SA. They also recommended repetitive testing over a period of time in order to account for the dynamic nature of most tasks (Salas et al., 1995, p. 132). This ensures that assessments capture the totality of the situation and the team's SA throughout task execution. Most team SA evaluation methods consist primarily of assessing and comparing individual SA in order to infer team SA because it is difficult to measure team SA in a holistic system approach as opposed to the sum of its parts (Salmon et al., 2008).

1. Endsley and Jones' Shared SA Evaluation Methodology

Endsley and Jones (1997) proposed a methodology that compared individual SA assessments between team members in order to assess shared SA. The potential comparisons of shared SA were then categorized and are depicted in Figure 12.

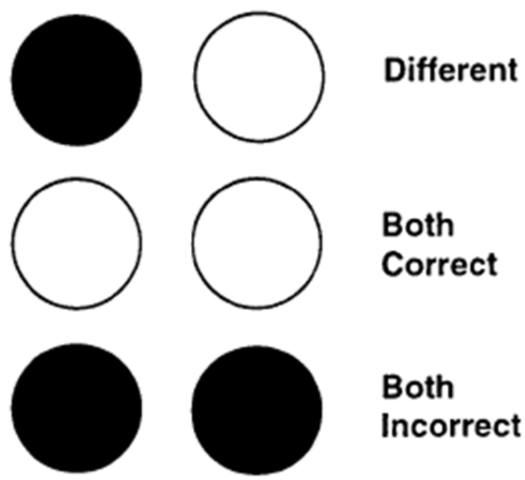


Figure 12. Possible Shared SA States. Source: Endsley and Jones (1997).

In 2002, Endsley and Jones expanded the number of possible states to five. While shared SA is a major component of team SA, this method fails to account for team member backup of individual SA or provide anything beyond binary evaluations of SA, which is insufficient with complex systems. Saner et al. (2009, pp. 283–284) asserted that true shared SA was impossible in the third state (similar but inaccurate), but while this statement may be correct, it is not useful during assessments to dismiss those results. Shared but inaccurate answers indicate that there is a failure somewhere in the SA collection process, but may also indicate successful team mechanics. The following list shows the five potential shared SA states.

- Both team members answer correctly—indicates accurate shared SA.

- Team Member A answers correctly, but Team Member B answers incorrectly—indicates non-shared SA.
- Team Member B answers correctly, but Team Member A answers incorrectly—indicates non-shared SA.
- Neither team member answers correctly, and their wrong answers are different—indicates team members have different SA and neither is correct.
- Neither team member answers correctly and their wrong answers are essentially the same—indicates inaccurate but shared SA (Saner et al., 2009, p. 282).

2. Saner, Bolstad, Gonzalez, and Cuevas' Individual SA Measurement

Saner, Bolstad, Gonzalez, and Cuevas (2009, p. 281) expanded individual SA measurement techniques in order to measure shared SA in a military rescue training exercise. They focused on the accuracy of individual SA and the comparison of individual SA between team members regarding shared responsibilities (Saner et al., 2009, p. 281). Accuracy of individual SA is good but useless to the team if not shared, and similarly, shared SA is good but useless if inaccurate. They built on Endsley and Jones' (2002) shared SA levels by proposing gradient measurement to accurately describe the accuracy or similarity of shared SA (Saner et al., 2009, p. 281). They narrowed the scope of their study by using direct measurement focused on SA as a product vice indirect measurement that focuses on the SA generation process.

While this is a valid technique for evaluating SA, it is insufficient for UTACC's purposes. UTACC will require assessments that drill down to the root causes of SA failures so that robot and team design can be corrected once those failures are identified. The *why* of SA failures is the ultimate goal, not the *what*. The focus on degree of shared SA is important though, as two different UTACC configurations may each generate an objectively equivalent amount of correct shared SA but differing degrees of incorrect SA. Here, degree comparisons can differentiate between the two configurations. Extending that idea, the degree of usefulness of SA elements toward task accomplishment should also be assessed. It may require a certain amount of subjectivity, but the benefit would be found in the allocation of resources. Assessments should focus not just on the accuracy and similarity of shared SA, but also on the usefulness of that SA.

3. Sulistyawati, Chui, and Wickens' Team SA Evaluation

Sulistyawati, Chui, and Wickens evaluated team SA in a simulated air combat scenario based on Endsley's levels of SA. They assessed awareness of situations relevant to own responsibilities, awareness of situation relevant to team member responsibilities, self-awareness of own SA, and awareness of team member SA and workload levels (Sulistyawati et al., 2008, p. 464). Additionally, they measured teamwork behaviors in order to correlate team performance and team SA. They utilized a combination of SAGAT questionnaires, self-appraisals, appraisals of teammates, and TARGETs scoring to build a holistic picture of SA failures and any associated teamwork behavior breakdowns in order to find their correlations. While their intent was to confirm correlations between team performance and team SA, their methodology would be excellent for UTACC in determining the root causes of team SA breakdown, be they team behavior failures or otherwise. This would allow UTACC to correct the manned–unmanned fire team by making the most appropriate changes to robot design, team organization, or teamwork behaviors: technology, people, or procedures. The authors also believe that the Sulistyawati et al. (2009) model and methodology provide an appropriate connection between team SA and the Coactive Design principles of observability, predictability, and directability that UTACC uses for interface design.

J. CHAPTER CONCLUSION AND SUMMARY

This chapter summarized the prevalent and most relevant SA definitions, models, and evaluation techniques. Endsley's three-level model of SA and SAGAT evaluation method are prevalent and tested in the military environment. Her work also forms the foundation for much of the follow-on work on individual and team SA. While it may lack the theoretical completeness of Smith and Hancock's perceptual cycle model, it is much easier to assess in complex dynamic environments. Endsley's model of team SA provides a useful distinction between individual and team SA requirements but lacks the utility offered by the Sulistyawati et al. model (2009). The majority of SA study involving human–robot interaction (HRI) has cast humans as operators vice true team members, which limits applicability to the UTACC program.

III. RESEARCH METHODOLOGY

In 2013, the MCWL began exploring multi-agent human–robotic teaming through the UTACC program. Zach (2016) used previous UTACC work based on the BAMCIS (begin planning, arrange reconnaissance, make reconnaissance, complete the plan, issue the order, and supervise activities) troop leading steps to apply Coactive Design through the use of IA tables. He determined the "special information exchange requirements between Marines and machines that ought to be implemented into the UTACC system" (Zach, 2016, p. 31). In 2016, MCWL changed the domain from the reconnaissance mission set to the infantry mission set with the goal of integrating robotic teammates into the Marine infantry fire team as a replacement for the automatic gunner role. Based on Marine Corps experience with both the positive and negative impact of technology on SA, particularly technology interfaces, the way forward was to determine the SA requirements involved within a Marine infantry fire team and to determine a method of evaluating robotic systems' impact on the SA of the fire team.

This thesis analyzed the predominant SA models related to the fields of task accomplishment, the infantry environment, and teaming in order to synthesize the models with the principles of Coactive Design and to provide models of SA specific to the UTACC project. This thesis also reviewed methods of SA evaluation in order to recommend the methods most useful to UTACC design and evaluation based on the synthesized SA models. The authors then analyzed doctrinal USMC mission training events in order to design a method for applying SA requirements analysis results to task breakdowns. Finally, the authors applied Johnson's OPD principles to the SA requirement task breakdown to determine interface design criteria to achieve the team SA requirements using IA tables.

To validate the synthesis of SA models and the incorporation of Coactive Design principles, Dr. Matthew Johnson, the originator of the Coactive Design Method, was sought to teach the authors how OPD would facilitate SA between humans and robots in a collaborative team environment. The authors conducted multiple instruction periods during visits by Johnson to NPS and validated their application of OPD to UTACC SA.

A. DEFINITION OF THE PROBLEM

UTACC's goal of eventually replacing a Marine with a UxS within the infantry fire team presents an evaluation problem. The Marine Corps trains and assesses its personnel and units using T&R evaluation events. A one-for-one replacement of a robot for a Marine might imply that one should use individual Marine metrics to evaluate the robot's suitability for the role, but Marines do not fight alone. They fight within a hierarchical command structure as units in order to achieve collective and nested goals. Individual task performance only matters as far as it contributes to the unit's mission accomplishment and unit capabilities are not simply a sum of the individual parts. While a robot that can perform every function of a human in the same manner and to the same level of performance may be ideal, from an evaluative comparison standpoint, it is neither realistic nor necessary. Rather, the robot should complement its human teammates in such a way that the unit as a whole accomplishes its tasks to at least the same level of human-only performance.

MCWL sought to determine a means to evaluate the impact of a robot's inclusion on the SA of a Marine infantry fire team. The proliferation of SA sharing technology on the battlefield has pushed the common operational picture from laptops in command centers to handheld devices at the lowest ranks of frontline units. These devices and interfaces can vastly increase the amount, type, and proximity of SA inputs received by frontline troops, but they also invite opportunity for narrowly focused SA that loses touch with the immediate surroundings. As such, military aviators call this narrowing of focus on sensor display interfaces at the expense of general flight SA as getting "*sucked in.*" Riley et al. (2008) highlighted this problem in their study of human operation of multiple robots:

> SA can be limited, though, in dynamic task environments by the availability of attentional resources. Allocation of attention to one stimulus over another may mean a loss of SA on certain elements of a task. In remote robot control, this means that operators must allocate attention to develop SA on both their local environment, and the remote environment. An operator's ability to develop good SA on the two environments simultaneously will be critically affected by the capability to divide attention across two places (Draper et al., 1998). An increase in attention

> allocation to the remote or local environment for achieving SA may mean loss of SA on the alternate environment. (Riley et al., 2008, p. 242)

The conundrum lies in the comparative value of the SA gains and losses provided by new technology. If a Marine's attention is sucked into a UAV feed displayed on his tablet while on patrol, he may miss visual indicators of an ambush that he would have seen if he was paying attention to his surroundings. Conversely, he may use the UAV feed to find the ambushers before he ever reaches human visual ranges if it scans the right location. Which is better? Ultimately, an interface that minimizes SA losses and maximizes SA gains is desirable, but given the choice between them, the comparison must be grounded in mission accomplishment.

Assume a trial scenario where a patrol of Marines utilizing the UAV scan, whose interface trades awareness in the near-field for awareness in the far-field, only find the ambushers half of the time but at a distance such that the Marines are able to avoid detection entirely. The other half of the time, the UAV scan is ineffective and the patrol is ultimately surprised due to a lessened awareness of the near-field, resulting in multiple casualties in which the patrol is forced to withdraw. Now assume that on a separate patrol, visual scanning without the aid of a UAV (therefore, with full near-field awareness) detects the ambushers 100% of the time, but at such close proximity that the Marines are detected every time. Despite being detected, the Marines still have enough forewarning to turn the ambush and push through without casualties. Without any context of the mission, the degree of SA in the unaided patrol appears to be the best.

Ultimately, however, only the effect on mission matters: which method allows the Marines to deal with the ambush in the context of their mission? If the Marines are conducting a raid in which the importance of avoiding detection is paramount, the UAV-aided SA scenario is now more useful. This is the mindset the authors want to endorse in the discussion regarding UTACC: it is not a comparison of apples to oranges—it is a comparison of how apples or oranges affect the mission.

UTACC's goal goes further than simply evaluating relative SA gains against one another. The project seeks to leverage the SA gains of technology in a way that does not degrade SA elsewhere. The ideal solution to the above scenario would be a collaboratively autonomous UxS that alerts the Marine when its scanning software finds a threat or anomaly. The Marine remains alert to his near-surroundings until directed to check his tablet for a threat. The result is that the Marines are still able to avoid detection 50% of the time, while now maintaining the ability to turn the ambush and avoid casualties the other 50% of the time because their SA was not "sucked." In the first scenario, the UAV was designed to provide a scanning function and given to Marines. Contrastingly, the ideal solution includes a UAV that was designed to collaborate with and support the Marines' mission environment.

Current SA models and evaluation methods are insufficient to account for the factors affecting UTACC in a useful evaluation method: the infantry environment, team SA, human–robot collaboration, and knowing what one does not know. This thesis attempts to synthesize multiple models of SA to develop a holistic model of SA that UTACC can use moving forward.

Endsley's model of SA is extensively tested in the military community and combines well with her SAGAT evaluation methodology. It has already been applied to the infantry operational environment. The authors believe her model is effective but lacks the completeness of Smith and Hancock's perceptual cycle model. By addressing SA as separate from situation assessment, emphasis is removed from the perpetual interaction between consciousness and schemata as the driver of SA and the state of knowledge that Endsley defined as SA. This is particularly important to the UTACC program because of the manned–unmanned teaming aspect. Robots are not Marines. Emphasis needs to focus on the schemata that drive SA activities in order to determine the design requirements for UTACC to provide a useful replacement for a Marine within a fire team.

Endsley's model of team SA is useful in differentiating individual team SA from shared SA, but lacks the understanding that there is an interplay between the two. It also does not provide a means of determining the why behind SA assessments, a facet that is uniquely important to UTACC due to their design requirements. The authors believe that applying Endsley's definition of team versus shared SA to the Sulistyawati et al. (2009) model provides the nuance required to do so.

B. SA MODEL

The authors combined the Endsley et al. (2000) infantry-centric SA model with Fracker's (1988) process of situation assessment and Smith and Hancock's (1995) perceptual model to attempt to create a more complete model. Endsley's model has been used extensively in SA evaluation, particularly in the military, but it lacks the underpinnings of process and consciousness that Fracker as well as Smith and Hancock offer. The authors synthesized Endsley and Jones' model of team SA with that of Sulistyawati et al. and applied it to the Marine Corps fire team organization.

C. TASK BREAKDOWN AND IA TABLE

Zach's (2016) work created a starting point for the application of Coactive Design to the UTACC project. Zach's (2016) method can be applied to derive the interface requirements once SA requirements have been determined. Zach's work, however, was based on the task breakdown of BAMCIS, which Rice et al. (2015) selected to support the reconnaissance mission environment. Given the change of mission environment to the infantry environment, a new task breakdown is required.

This thesis used the Marine Corps' Infantry T&R manual to select task event INF-MAN-3001: Conduct Fire and Movement (Appendix C) under the context of the higher goal event INF-MAN-4001: Conduct Ground Attack (Appendix D). The selected task and higher goal were distilled from the offensive portion of the mission of the Marine rifle squad. The purpose of the Marine rifle squad is to "locate, close with, and destroy the enemy by fire and maneuver, or repel the enemy's assault by fire and close combat. The offensive mission of the squad is to attack" (USMC, 2002, p. 4-1). The "conduct" phase of the offensive squad attack is further subdivided into the following steps:

1. Movement forward of the line of departure to the assault position.
2. Advance by fire and maneuver.
3. Arrival at the assault position.
4. Assault and advance through the assigned objective.
5. Consolidation and reorganization (USMC, 2002, p. 4-1).

The central three steps (2, 3, and 4) are the core of the attack phase, and the primary means by which the Marine fire team executes those steps is the method called fire and movement:

> Once the maneuver element meets enemy opposition and can no longer advance under the cover of the base of fire, it employs fire and movement to continue its forward movement to a position from which it can assault the enemy position. In a maneuvering squad, fire and movement consists of individuals or fire teams providing covering fire while other individuals or fire teams advance toward the enemy or assault the enemy position… The fire team, as the basic fire unit, is restricted to executing only fire and movement. (USMC, 2002, pp. 4-21–22)

The authors selected the “advance by fire and maneuver” phase as the situation environment. The fire team task of Conduct Fire and Movement was then broken into its doctrinal subtasks and applicable SA requirements were analyzed through an IA table to determine the interface requirements necessary to achieve OPD. The SA requirements were chosen from a study by Matthews, Strater, and Endsley (2004) that derived SA requirements for infantry MOUT operations (Appendix B). The format for the IA table along with cell descriptions is shown in Table 5 and the color legend for the color scheme is shown in Table 6.

Table 5. UTACC SA IA Table Format.
Adapted from Zach (2016).

					Present configuration: -Fire team leader (FTL), Automatic rifleman (AR), Assistant automatic rifleman (AAR), Rifleman (RIF) -Actions performed by AR, supported by FTL, AAR, RIF				UTACC configuration: -Fire team leader (FTL), Unmanned System (UxS), Assistant automatic rifleman (AAR), Rifleman (RIF) -Actions performed by UxS, supported by FTL, AAR, RIF				Mechanisms, interface design elements, etc. that meet the Observability, Predictability, Directability requirements synthesized through the analysis of the interdependent teaming role alternatives.
Tasks	**Subtasks and Description**	**Capacities**	**Level 1 SA requirement (METT-TSL)**	**SA requirement justification**	**FTL**	**AR**	**AAR**	**RIF**	**FTL**	**UxS**	**AAR**	**RIF**	**OPD/common ground/shared mental model requirements & comments**
(A) Task	(A.1) Subtask of Main Task (A) Description of Subtask (A.1)	Functional actions to accomplish Subtask (A.1)	METT-TSL Level 1 SA Requirements for Subtask (A.1) Mission (A.1.M.1), Enemy (A.1.E.1), Terrain and Weather (A.1.TW.1), Troops & Fire Support available (A.1.TFS.1), Time available (A.1.TA.1), Space (A.1.S.1), OR Logistics (A.1.L.1)	SA requirement justification for (A.1.X.1) Why is the requirement important i.e., what comprehension can be gained from it?									Mechanisms, OPD, etc. for (A.1.X.1)
			(A.1.X.2)	SA requirement justification for (A.1.X.2)									Mechanisms, OPD, etc. for (A.1.X.2)
	(A.2) Subtask of Main Task (A) Description of Subtask (A.2)	Functional actions to accomplish Subtask (A.2)	(A.2.X.1)	SA requirement justification for (A.2.X.1) and (A.2.X.2)									Mechanisms, OPD, etc. for (A.2.X.1) and (A.2.X.2)
			(A.2.X.2)										
			(A.2.X.3)	SA requirement justification for (A.2.X.3)									Mechanisms, OPD, etc. for (A.2.X.3)

In Table 5, all columns for interdependency color-coding are from a supporting team member perspective with the exception of the automatic rifleman (AR) and the UxS. The FTL, assistant automatic rifleman (AAR), and the rifleman (RIF) columns indicate these supporting team member roles. The UxS and AR interdependencies are as the supported team member, or the performer. Therefore, UxS and AR column headings are shaded gray as opposed to black in order to differentiate the performing team members from the supporting team members.

Table 6. UTACC SA IA Color Scheme.
Source: Zach (2016).

Performer	Supporting Team Member
I can do it all	My assistance could improve efficiency
I can do it all but my reliability is < 100%	My assistance could improve reliability
I can contribute but need assistance	My assistance is required
I cannot do it	I cannot provide assistance
Not applicable	Not applicable

D. CHAPTER CONCLUSION AND SUMMARY

This chapter began by outlining the issue faced by the UTACC program in assessing the impact of robotic team members on Marine Corps fire team SA. Synthesized models of individual and team SA were selected to resolve the issues with current models for UTACC purposes. An example task was selected from the Marine infantry fire team operational environment so that Coactive Design principles could be applied, and then Zach's (2016) IA table framework was modified to address SA. The change of the mission environment precipitates the need for a new task breakdown and underscores the importance of conducting detailed IA for subsequent changes and derivations within an infantry context. The next chapter will explore the synthesized SA models and the results of applying the Coactive Design methodology to team SA requirements.

IV. UTACC SA MODELS AND COACTIVE DESIGN RESULTS

This section describes the results of synthesizing various situation awareness models and applying Coactive Design to UTACC task breakdowns and SA requirements. This overview will focus on the unique implications of UTACC on individual and team SA models and on the results of adapting Zach's (2016) UTACC IA table methodology to SA requirements.

The individual SA model was adapted from Endsley's Situation Awareness model in order to capture the holistic approach of Smith and Hancock's Perceptual Cycle model. The team SA model was adapted from Sulistyawati et al. (2009) and focuses on the unique role of the fire team leader during team SA interactions. The authors constructed the task breakdown from doctrinal USMC T&R events, a task structure that is organic to the Marine Corps. An IA table was developed for event "INF-MAN-3001: Conduct fire and movement," which is a core task of the infantry fire team across the spectrum of the infantry situations.

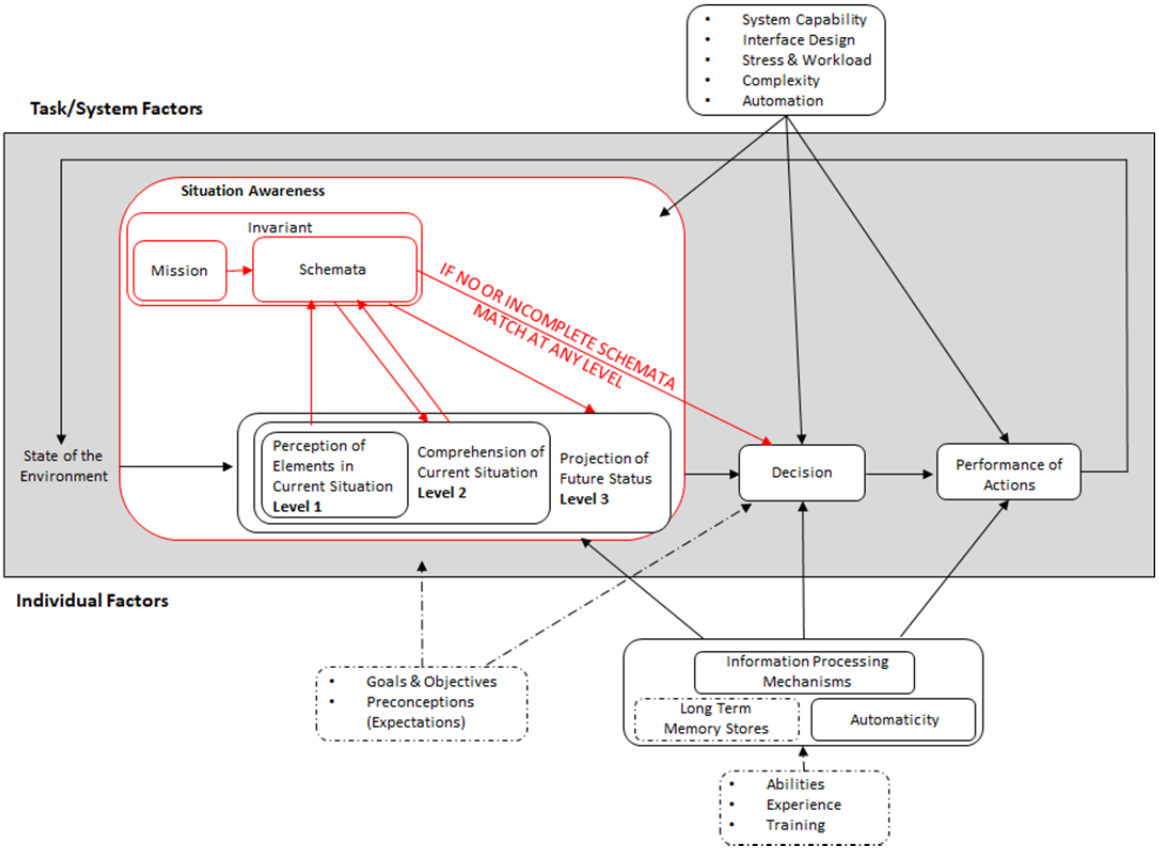
Due to the size of the IA table, this chapter discusses the first subtask, "Suppress the enemy" in detail, as well as results applicable to the whole task. The subtask IA table is partitioned into multiple sections for ease of discussion. The entire IA table can be found in Appendix E.

A. INFANTRY/INDIVIDUAL SA MODEL EXPANSION FOR UTACC

Endsley drew a distinction between SA as the state and situation assessment as the process of building SA (Endsley, 1995 p. 36). The authors find Hancock and Smith's holistic model to be more complete, but also recognize that Endsley's model is more useful for measuring SA, particularly in the military environment. SA is often evaluated as part of training, but the assessment process itself is often not evaluated beyond the mechanics of situation assessment actions. The value of schemata is clearly understood and promulgated through the use of professional military education, case studies, professional reading lists, operational scenario exercises, and training evolutions, but rarely do SA evaluations try to track the application of those schemata to the situation. In part, this is likely due to the inherent difficulty of doing so. The ability to measure the assessment process in humans is likely fraught with bias and memory problems that would make it difficult to generate usable results. It would be extremely difficult if not impossible to quantify the multitude of inputs that human schemata are created from. It is also likely impossible for individuals to accurately remember every schema that they used to build SA in complex and dynamic environments.

UTACC faces a new opportunity in regards to the situation assessment mechanics. Robots are programmed, so memory and decision-making can be traced, recorded, and analyzed. To this end, the authors proposed adapting Endsley's model to include schemata and working memory interactions as part of SA instead of just as mechanisms of SA. The authors' adapted model of SA is depicted in Figure 13. Viewing SA as the interaction between schemata and the state of knowledge will help UTACC better understand the cognitive paths and models used by the robots so that design and programming can be corrected, refined, and updated.

The other change the authors propose to Endsley's model is the placement of the mission. Endsley called this "goals and objectives" and lumped it in with individual factors, but the authors propose that the mission should be the central starting point of the model because SA cannot exist without an externally oriented task, goal, or objective (Smith & Hancock, 1995, p. 140). The mission is both the purpose and the context of SA. Before any information is retrieved from the environment and before any planning is conducted, the mission must be understood. SA does not occur in a vacuum. Understanding of the mission determines the selection of the initial schemata that supply the beginning preconceptions that will in turn drive SA decisions and actions until information can be retrieved from the environment.



Dashed boxes are subsumed into mission and schemata boxes

Figure 13. Proposed Model of Individual SA. Adapted from Endsley (1995)

B. COMMON GROUND

UTACC will face multiple technical issues in the integration of robots into Marine fire teams, but one of the most significant regarding SA will be the communication of SA from robots to Marines. Humans and robots currently lack a common language beyond what robots are programmed to understand, which limits the available common ground used during communications. Marines who lack a common mental model or common terminology have rich aural and visual interfaces available to overcome this shortfall. Until robots are capable of understanding naturalistic language and interpreting visual representations on a human level, this will continue to be a limitation. The best method to overcome this limitation is to use the same method Marines currently use which is making use of their own common language in order to avoid the need for plain language explanations.

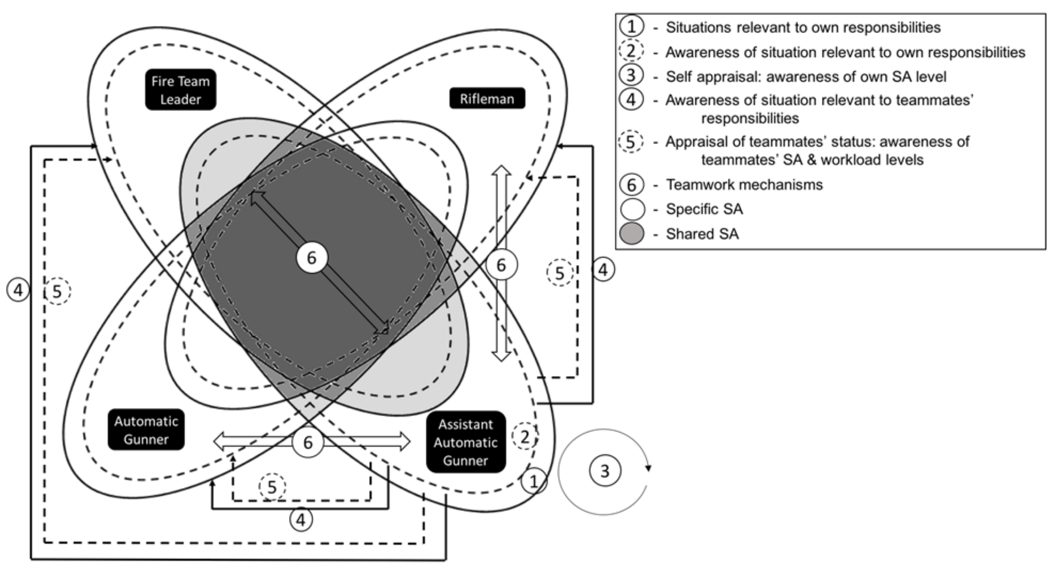
UTACC should design its robots to understand and operate using the constructs that are already in use. Acronyms like METT-TC, ADDRAC, and OSMEAC are more than just acronyms. They categorize and convey information in a manner understood by all Marines. Communication formats like calls for fire, CAS and MEDEVAC 9-lines, or IFREPs convey information in a common, expected, and efficient manner between different specialties. These constructs are a bridge between groups with different mental models. UTACC should design the robots to classify and communicate SA data according to Marine Corps and joint terminology and constructs in order to maximize common language and shared mental models. SA assessments then can be used to identify gaps in common language and develop procedures to overcome those gaps.

The programming that selects the correct terminology or communication procedure will need to be capable of understanding zones of interest and levels of abstraction, or proximity and perspective. Proximity does not just mean physical or temporal distance; it also means the priority of the information based on its impact to the mission. Understanding this definition of proximity allows the robot to select the best communication construct to convey the information. A robot may process location data in absolute terms, but if the information is about an enemy in close proximity to the fire team, the robot should pass that information to the fire team leader in relative terms because that is the most useful format at that moment. If the enemy location proximity is far enough away that there is no immediate threat, absolute coordinates may be more useful. This level of understanding would require the robot to achieve Level 3 SA in relation to the recipient, not just for itself.

The perspective of the recipient is key: for example, passing azimuth data to a pilot in mils is unduly burdensome because the pilot’s instruments use degrees. An artillery Marine, however, would prefer mils for the same reason. In the UTACC scenario, this is comparable to passing relative versus absolute locations. The relative location is more useful to the fire team leader, but absolute location is more useful for passing information to higher echelons of command, such as the battalion operations center.

C. TEAM SA MODEL

Endsley and Jones' (1997) model of team SA provided a useful distinction between two categories of externally oriented SA: team SA and shared SA. In order to avoid confusion between Endsley's definition of team SA and the general topic of team SA, the authors use the term "specific SA" to define those SA requirements that are specific to a single individual within a team. The term "team SA" refers to the overarching group SA that is composed of specific and shared SA. Sulistyawati et al, in 2009, expanded Endsley and Jones' view of team SA as overlapping individual SA by addressing the intrateam SA that is also part of the larger team SA. The authors used the model of Sulistyawati et al. with Endsley's distinction between shared and specific SA to form a four-person Marine fire team SA model. The view from a single fire team member's perspective is shown in Figure 14.



Ellipses were used as opposed to circles in order to display all possible iterations of shared SA. Circles suffice for depicting shared SA regions between three members, but not for teams of four members

Figure 14. Model of Team SA from a Team Member's Perspective. Adapted from Sulistyawati et al. (2009).

When viewed from any member's perspective other than that of the fire team leader, the model is not fundamentally different from that of Sulistyawati et al., merely adapted from two to four members. When viewed from the fire team leader's perspective, however, the authors found an aspect of team SA that Sulistyawati et al., did not directly address: the leadership role. Theoretically, a team can be composed of equally responsible individuals. This is never the case in the military chain of command; there is always someone in charge and that individual is responsible for the entire team. "The chain of command establishes authority and responsibility in an unbroken succession directly from one commander to another. The commander at each level responds to orders and directions received from a higher commander and, in turn, issues orders and gives directions to subordinates" (USMC, 1996, pp. 87–88) The commander is also responsible for and directly involved in the coordination that occurs between subordinates.

In the member perspective model depicted in Figure 14, only those shared SA portions that directly affect that member are shaded. The commander of the team, in this case the fire team leader, is responsible for more than just the shared SA portions that directly affect himself. Commanders are responsible for the entire shared SA within the team, so they must have some level of SA over those overlaps, even if the overlaps do not directly affect the fire team leaders' specific responsibilities. The authors attempt to capture these additional aspects of the team leader in Figure 15, in which the model is depicted from the perspective of the fire team leader. A team encompassing boundary has been added to indicate the team's total responsibilities; an additional assessment loop has been added to represent the fire team leader's assessment of the total team SA; and every shared SA overlap is shaded, not just those portions that directly impact the fire team leader's specific responsibilities.

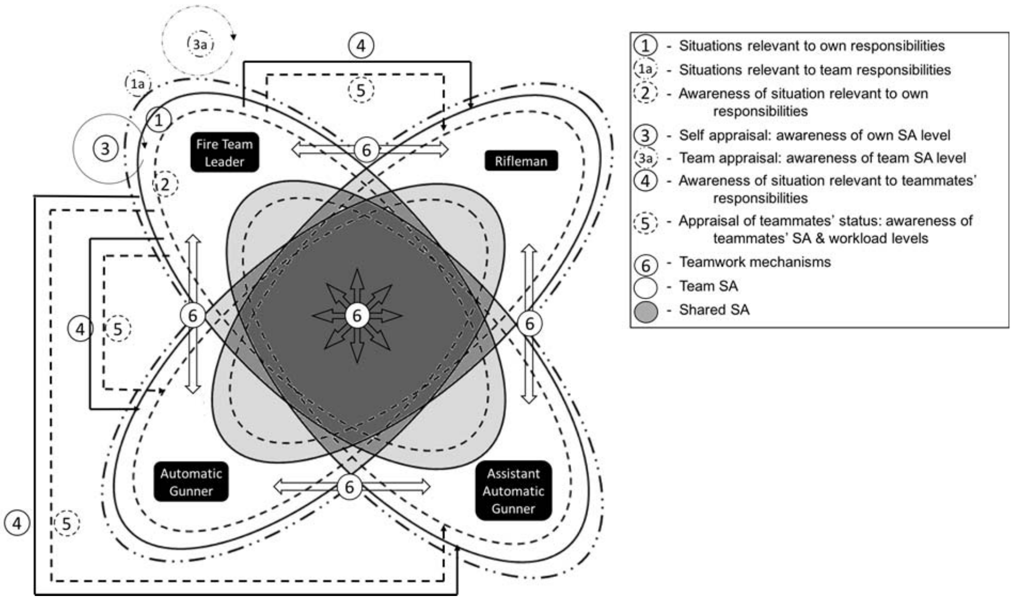


Figure 15. Model of Team SA from the Fire Team Leader's Perspective. Adapted from Sulistyawati et al. (2009).

While the leadership impacts on the team SA model have implications for military team SA evaluation, they are not specific to UTACC's problem: interdependent collaboration between human and robotic team members. UTACC faces a unique challenge in incorporating collaborative robots into Marine fire teams. Even if the design of the robot accounts for individual SA requirements, UTACC could easily miss the mark if design does not account for team SA requirements. The specific implications of team SA are the awareness and appraisal of teammates' responsibilities, SA, and workload levels; and the associated team mechanisms. The challenges of HRIs raise significant questions: How will Marines assess a robotic teammate's SA and workload? How will Marines share SA information with a robotic teammate? How does the fire team leader judge the level of shared SA between the Marines and the robot? The authors propose that by using task breakdowns, SA requirements analysis, and Coactive Design IA tables focused on team SA, one can identify the specific gaps to overcome. Design using OPD can then identify the necessary changes to organization, procedures, or technology needed to achieve the team SA and task requirements.

D. INTRATEAM SA AND OPD

Applying Endsley's three levels of SA to intrateam mechanisms demonstrates the justification for OPD. The levels of SA and their applicability to OPD are shown in Figure 16.

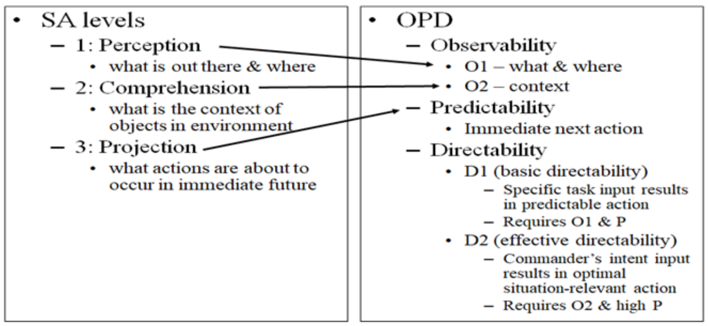


Figure 16. Levels of SA Applied to OPD.

Perfect autonomy results in undesirable opacity between team members. In a human–robotic team, it is unacceptable. Application of OPD principles to team interface design will generate the intrateam visibility that is necessary in the infantry fire team.

E. CONDUCT FIRE AND MOVEMENT IA TABLE

The first subtask of the USMC infantry T&R event "INF-MAN-3001: Conduct fire and movement" is "suppress the enemy" (DON HQ USMC, 2013, p. 7-50). The authors categorized the SA requirements in this subtask by mission, enemy, terrain and weather, troops and fire support, time available, space, and logistics (METT-TSL). The authors selected SA requirements from a large pool of Level 1 infantry MOUT SA requirements based on their applicability to the particular subtask. There are significantly more SA requirements than those depicted here (see Appendix B), but while useful, they are not necessary to the successful accomplishment of the specified task and subtasks. The fifth column of the SA IA tables (format shown in Table 5 and applied in Tables 7), titled SA requirements justification, is where readers can find the authors' reasoning for the requirements selection. Readers should view the justifications through the lens of Levels 2 and 3 SA—comprehension and projection gained from the Level 1 elements found in the environment.

The OPD requirements focus on the technological challenges involved with implementing HMI that supports current organization and procedures in the Marine Corps infantry operating environment, which is often austere and isolated from significant logistical support, particularly when viewed in the context of distributed lethality like the MEU Company Landing Team concept. While adjustments to procedure or organizational structure could overcome some of the technological challenges, the focus should be on solving the technological hurdles in order to enhance current procedures and organizational structures, not sub-optimizing procedures to accommodate for technological limitations. This should not imply that procedural or organizational changes that capitalize on technological capabilities should be discouraged; in fact, they should be encouraged when they result in a net gain to the fire team's effectiveness.

1. Mission SA Requirements

The mission SA requirements form the context of the task. The comprehension and projection gained through mission SA drive all SA-related actions during task execution. Marines use the five-paragraph Orientation, Situation, Mission, Execution, Administration & Logistics, and Command and Control (OSMEAC) format for orders generation and dissemination. Marines convey orders information through various mediums, including written, aural, or electronic, and often involve visual aids such as diagrams, maps, and models. The authors selected mission objective, objective location, commander's intent, course of action / scheme of maneuver, priorities of targets, and assignment of targets as the necessary mission SA requirements. While true understanding of the mission objective and commander's intent SA requirements would equal comprehension, the focus here is on the statements of mission objective and commander's intent that must be perceived before they can be comprehended. Marines use a prescriptive set of defined tactical mission tasks combined with timing and locations in order to convey specific and clear actions understood by all (USMC, n.d., p. 7). Commander's intent is less directive but structured by purpose and end state in order to allow flexibility in action as long as it satisfies the intent of the mission (USMC, 2011, p. 89). The mission SA requirements and OPD implications are depicted in Table 7.

Table 7. IA Table: Mission SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assaults momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.M.1) Mission objective	Context: what is the larger mission objective and how does suppression support mission objective? At minimum, FT must understand the next higher level (squad) task.									Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.1.M.2) Location of objective	Where is the objective in relation to suppression?									Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.1.M.3) Commander's intent	Context: why conduct this mission?									Machines may never understand this, or at least take a long time
			(A.1.M.4) Course of action / scheme of maneuver	Context: how does this task fit into scheme of maneuver?									Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.1.M.5) Priority of targets	Which types or specific targets are high value/payoff? If multiple targets present themselves, which should be engaged first? (Automatic gunners would typically focus on enemy automatic weapons over riflemen).									Directability: FTL needs capability to communicate target priorities to UxS. Observability: FTL needs capability to confirm UxS receipt of priorities. Predictability: Confirmed when UxS selects targets based on priorities. Achieved through training/experience with dynamic targets of varying priorities. Doctrinal for human AR. Current UxS could be programmed with priority targets but may struggle with application during execution. If machine can identify and distinguish targets by function/capability, it could execute this task with less or without assistance. Machine learning can overcome ability to identify enemy uniforms, vehicles, weapon systems visually/aurally. If machine could assess priority targets during execution and had access to distributed target data or camera feeds from other team members, could dramatically assist with assessing priority targets based on larger picture of the whole team.
			(A.1.M.6) Assignment of targets	Which targets did the FTL assign to the AR? Which targets are assigned to other FT members?									Directability: FTL needs capability to assign targets to UxS. Observability: FTL confirms receipt of target assignment by observing UxS fires - no different than with Marine. Predictability: Built through training and experience of target assignment & resultant actions. UxS should expect target assignments from FTL & needs to monitor FTL for assignments/updates during actions. If machine could process enemy targets, friendly locations, boundaries, COAs, etc. then machine may be able to optimize target assignments and feed info to other members. If UxS is currently incapable of identifying targets and implementing target assignments independently, a "gun buddy" UxS that follows a particular Marine and shoots what that Marine shoots may achieve intermediate progress (could be conducting machine learning for future capability at same time). Gun buddy UxS could feed Marine information from its sensors through various heads up interfaces that could support a hybrid Marine/machine buddy team that optimizes combination of robotic gains with Marine cognition and decision-making.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

The OPD requirements drawn from the mission SA requirements focus on the HMI that supports current Marine orders processes. The primary takeaway is that the fire team leader must be capable of communicating orders to the UxS, the UxS must provide acknowledgement of orders receipt, and the orders should have some predictable effect on the UxS's actions. The orange coloration of the AR performer reflects the doctrinal role of the FTL in the chain of command, but the AR may receive mission orders at the same time as the FTL and need very little actual mission instruction from the FTL. UxS network and interface capabilities may be able to achieve the same effect and provide some efficiency (e.g., UxS downloads mission plans of higher levels and seeks updates/clarification from FTL on specific parts).

2. Enemy

The enemy SA requirements are at the core of the suppress subtask. Suppression is an enemy-oriented tactical task that depends on perception of enemy disposition. Marines cannot suppress the enemy if they cannot locate the enemy. During mission planning, Marines use size, activity, location, unit, time, and equipment (SALUTE) to organize enemy disposition information at the perceptual level. Comprehension of enemy capabilities is categorized according to the tactical tasks defend, reinforce, attack, withdraw, and delay (DRAW-D), and projections of enemy courses of action are divided into the most likely and most dangerous (EMLCOA and EMDCOA, respectively). While comprehension and projection of enemy courses of action may be difficult for machines to master, collecting enemy disposition data and comparing it to expected enemy disposition may be one way in which the UTACC UxS can provide a significant value at the fire team level. The enemy SA requirements and OPD implications are depicted in Table 8.

Table 8. IA Table: Enemy SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.E.1) Enemy disposition (location, dispersion, numbers, weapons)	What does the enemy footprint look like, and what part of the enemy is the FT facing?									Directability: FT members need capability to communicate enemy disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Utilize ADDRAC, SALUTE, DRAW-D, EMLCOA, EMDCOA etc to standardize information. Depends on UxS sensor capability to perceive & processing power to comprehend targeting info from sensor feeds. Machine learning can overcome inability to identify enemy uniforms, vehicles, weapon systems visually/aurally. UxS may be more capable than Marines at identifying enemy disposition info based on time limited or partial observations of enemies. If all Marines had cameras, UxS could process distributed enemy disposition data and communicate it to all FT members.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

Through machine learning of enemy visual and aural signatures, the UTACC UxS could perceive enemy disposition information in more spectrums and with higher accuracy with far shorter exposure than Marines could. A Marine's FOV is limited to the forward aspect, but a UxS does not have to have the same limitation. UTACC UxS could provide constant 360-degree surveillance and alert Marines to enemy contact from any direction. The Marines use the mnemonic "alert, direction, description, range, (target) assignment, and (fire) control" (ADDRAC) to cue fellow Marines to enemy contact. Depending on how well the UxS can understand target priorities and assignments, the FTL could offload a significant amount of target assignment management to the UxS, freeing the FTL to focus on his other responsibilities.

UxS could also significantly improve the enemy disposition information reported to higher by automating the process. The digitization of reporting from the lowest levels would also allow for reconciliation of enemy disposition reports by algorithms instead of relying solely on human judgement and cross-referencing.

3. Terrain and Weather

Both halves of "fire and movement" involve significant interaction with terrain and terrain features. Marines must move across terrain while seeking cover from enemy fire behind terrain features. For the other half, Marines must account for terrain effects on weapon ballistics and the enemy's use of terrain cover on the effectiveness of friendly suppression. Marines use observation, cover concealment, obstacles, key terrain, avenues of approach, and weather (OCOKAW) to categorize important terrain features during planning. The terrain and weather SA requirements are depicted in Table 9.

Table 9. IA Table: Terrain and Weather SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.TW.1) Type of terrain (hilly, flat, mountainous, urban)	Terrain type impacts rate of movement, visibility, fire control, and tactics.									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
			(A.1.TW.2) Terrain features (obstacles, enemy cover)	Terrain features affect fields of observation, avenues of approach, rate of movement, and available cover.									

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

A detailed perception of the terrain is necessary for the UxS to comprehend possible movement routes and cover in the environment. It is also necessary for the judicious application of suppression against those enemy targets that are in the best position to affect friendlies exposed to enemy fire during the act of movement or maneuver. By perceiving the terrain elements around it, the UxS can comprehend their applicability to movement and cover, predict friendly movement, compare to enemy fields of observation, then prioritize the optimal targets to suppress.

4. Troops and Fire Support

Troops and fire support SA requirements focus primarily on the UxS's ability to understand its position and role relative to other friendly forces. The UxS would compare current friendly dispositions and fires to planned dispositions and fires in order to build comprehension and projection. Toward this aim, the authors selected friendly disposition, friendly movement, areas/timing/types of planned fires, areas/timing/types of current fires, and direction of fires as SA requirements. They are depicted in Table 10.

Table 10. IA Table: Troops and Fire Support SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.TFS.1) Friendly disposition	It is a team task. Must be able to know position relative to FT members and adjacent/higher units.									Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
			(A.1.TFS.2) Friendly movement (in relation to suppressive fires)	Suppression has a purpose. Here it is to allow other FT members to move to next covered position. Suppression be focused on enemy targets that would interfere with that movement.									
			(A.1.TFS.3) Areas/timing/type of planned fires	What is the overall fires plan? Are any other planned fires going to achieve FT-specific suppression needs? How does this suppression fit into overall fires plan? Are there specific trigger down times/cooling periods/etc associated with suppression?									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: FTL needs capability to confirm UxS receipt of fires plan (ex: "Robot, what is your part of the fires plan?"). Predictability: UxS should have selectable permissions on starting/stopping fire (wait for a Marine to shoot first, cease fire if Marines cease fire, execute fires on order/timing/event, etc). FTL must assign for UxS (significant potential for interface drain on SA in combat situation). Ideal UxS could interpret aural and visual commands/signals just like Marines. Robot can help FT members keep track of planned fires during execution. Robot could also be central hub for fires alerts coming to team in execution.
			(A.1.TFS.4) Areas/timing/type of current fires	What fires are actually occurring? Is necessary suppression being achieved by other fires? Is any adjacent/higher suppression not occurring as planned and does it affect FT suppression?									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e., RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (ie if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression). Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are shooting IOT not interrupt their firing.
			(A.1.TFS.5) Direction of fires (other friendlies)	Adjacent fires may indicate unseen targets. Fire and movement suppression is an alternating task between buddies or buddy pairs - if assuming suppression from prior FT member, what were they suppressing? That is probably what the AR/UxS should suppress.									

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

Troops and time available SA requirements have a close relationship with the mission SA requirements, and rely heavily on the ability to perceive friendly positions and firing data. Current UxS abilities to perceive these actions rely on active sensors that create two major risks: exposure of friendly presence and disposition through EM radiation or enemy penetration of friendly force tracking networks. These risks are not unique to UTACC and already exist on the battlefield with the proliferation of radios and network systems to the lowest echelons that enable force tracking through systems like Blue Force Tracker. The main difference is that Marines can and do operate without networked systems when the situation dictates. UTACC's UxS will need to improve its passive capabilities in this arena in order to be usable during varying levels of electronic warfare. Networked capabilities should not be neglected, however. When the situation allows network activity, the networked capabilities of a UTACC UxS could bring significant SA to the fire team and provide significant advances in fire coordination at multiple force levels.

5. Time Available

The time available category is relatively broad, but for the purpose of the subtask "suppress the enemy," the authors focused on the planned rate of movement. The time available SA requirement is depicted in Table 11.

Table 11. IA Table: Time Available SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.TA.2) Planned rate of movement	Interdependence between suppressor and mover									Directability: FTL needs capability to communicate planned rates of movement to UxS. FTL needs capability to order specific rates of movement for UxS. Observability: FTL needs capability to query UxS ability to achieve planned rates of movement. Predictability: UxS needs library of UxS and Marine rates of movement across varying terrain. UxS can assist with countdowns until clear, expected timing of suppression for movement rates and distances, and movement planning to meet time constraints.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

Planned rate of movement can mean several things depending on the level of abstraction. It may mean the overall pace of the operation (e.g., a rapid raid versus a more methodical clearing mission), the expected duration of a buddy rush (Marines use the mnemonic "I'm up, they see me, I'm down" as a measure of upright rush timing), or the maximum rate of movement the UxS or Marines can sustain over different amounts of time and different terrain. Comprehension from the planned rate of movement SA requirement is tightly coupled with mission planning and terrain and weather SA requirements due to the impact that they have on planned or possible rates of movement. A UxS could provide significant support to the FTL in calculating expected rates of movement based on terrain impacts or recommending optimal routing based on time constraints, which would also provide higher levels of command with a much better picture of troop movements.

6. Space

The space SA requirements primarily focus on the artificial limits of the battlespace. The space SA requirement is depicted in Table 12.

Table 12. IA Table: Space SA Requirements

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.S.1) Areas of operation/boundaries & fire support control measures	Context: how do FT & task fit into and affect larger/adjacent units & tasks? Must adhere to boundaries during task & subtask.									Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

The primary challenge associated with battlespace boundaries and fire support control measures (FSCMs) lies in the medium used to convey them. Some are described textually with grid coordinates, a relatively simple form for a UxS to translate. Other boundaries and FSCMs, however, often follow terrain features or do not have straight edges, and are depicted graphically on maps. While electronic, map-based planning systems can create complex boundaries and FSCMs, these systems will not always be available in austere infantry environments. UTACC should focus development on the UxS's ability to perceive and comprehend the different boundary ops terms and graphics in order to receive information from disseminated imagery and maps. Once the UxS can do this, it can provide significant adherence or event triggered action support to the FTL during task execution.

7. Logistics

The logistics SA requirement for suppression is relatively simple: ammunition level. Since the authors are focused on mission-oriented SA requirements, they assume that those UxS logistics requirements that pertain to "health and welfare" of the UxS would be monitored and communicated in the background while the mission is being executed.

The volume of fire that can be maintained over the necessary time period that suppression is needed is dependent on ammunition level. The ammunition level SA requirement is depicted in Table 13.

Table 13. IA Table: Logistics SA Requirement

Tasks	Subtasks and Description	Capacities	Level 1 SA requirements (METT-TSL)	SA requirements justification	FTL	AR	AAR	RIF	FTL	UxS	AAR	RIF	OPD/common ground/shared mental model requirements & comments
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and the moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.L.1) Ammunition level	Ammunition level affects rate/volume of fire, especially when cross-referenced with distance to objective and rate of movement.									Directability: FTL needs capability to dictate ammunition conservation. Observability: FTL needs capability to observe UxS ammunition level. Utilize standard prowords "shotgun," "winchester," etc to indicate particular ammunition states Predictability: FTL needs to capability to select actions/settings based on ammunition level (ex: at "shotgun" request resupply & at "winchester" move to AAR for reload assistance). If machine could track team's ammunition and alert members when to change mags before certain pushes, etc. They can also alert logistics quickly and automatically that team needs resupply.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

This SA requirement demonstrates an area where the UxS is just as capable as the Marine AR and may possess significant advantages. A simple ammunition counter can precisely monitor ammunition levels more accurately than a Marine can, and the UxS could calculate the appropriate rates of fire and burst timing to provide the optimal suppression over variable times. Several other possible advantages are discussed in the rightmost column that would depend on the level of networked systems within the team. The risks are similar to those discussed previously in regard to friendly disposition tracking; however, the gains may very well be worth the risk. A UxS could help manage ammunition distribution throughout the fire team and send preemptive requests for ammunition resupplies to higher or adjacent units based on projected expenditures, instead of the FTL waiting until ammunition reaches critical levels or reaching the consolidation phase.

F. CHAPTER CONCLUSION AND SUMMARY

This chapter began by presenting the authors proposed individual and team SA models for UTACC. The critical takeaway from the individual SA model is that the mission is both the purpose and the context of SA. The UTACC initiative presents the opportunity to more completely assess and evaluate the interactions between mission tasking, schemata, and the state of knowledge than was previously possible with human subjects. The authors recommend using all (and only!) USMC infantry common language in order to design UxS that more seamlessly integrate into infantry fire teams. Team SA assessment in the military environment must account for the unique role of the chain of command in understanding the intrateam relationships and activities that facilitate team SA. The subtask "suppress the enemy" portion of the IA table was discussed in order to provide a repeatable methodology for future SA and Coactive Design analysis. The entire IA table for the INF-MAN-3001 "conduct fire and movement" task can be found in Appendix E.

V. SUMMARIZING RESULTS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This thesis has two main impact areas. The first proposes models of SA for the UTACC environment. The other uses SA requirements analysis and Coactive Design to produce a list of design requirements that captures the team interactions that facilitate team SA at the fire team level. The authors focused on interface requirements for a UxS to function within the current Marine Corps infantry fire team construct. The authors' personal experiences as Marine Corps HMLA pilots had a significant impact on their interpretation of SA models, selection of SA requirements, and OPD design requirements/possibilities due to their experience with SA and HMI in the aviation environment. Though the authors received provisional rifle platoon commander training at The Basic School and closely supported infantry operations for several years, they are not infantry subject matter experts (SME). Future researchers should seek out infantry SMEs from the Marine Corps School of Infantry, Infantry Officers Course, and the Tactical Training Exercise Control Group Infantry Division for future SA requirements analysis.

A. SUMMARIZING RESULTS

Zach highlighted the usefulness that Coactive Design provides to the UTACC program:

> 'Coactive Design breaks with traditional human-machine design approaches by focusing on effective management of interdependencies verses focusing on autonomy.' It has a foundation in systems engineering and as an iterative design and development method is well suited to meeting the demands of a future military system where requirements will change throughout the development life cycle. (Zach, 2016, p. 75)

The use of Coactive Design to evaluate individual and team SA dynamics within the infantry fire team builds upon previous UTACC research by Zach along with Kirkpatrick and Rushing.

1. General Comments

Team mechanisms are central to effective team SA, and efficient team mechanisms rely heavily on shared mental models and common language. Marines spend years training together in order to operate as effective teams that function smoothly as a single entity. The successful integration of robotic teammates should not be expected to happen overnight—a UxS will likely need to train alongside Marines before human–machine infantry teams operate effectively and efficiently based on intrateam trust. Designing a UxS to think and communicate according to Marine common languages and models is the first step in the right direction.

The authors used T&R task breakdowns and SA requirements categorized according to METT-TSL to structure the team SA relationships under the Coactive Design lens. By using doctrinal structures with which all Marines are familiar, this thesis provides a repeatable method for situation-relevant experts to identify team interface requirements for UTACC designers. "This reduces the amount of system learning required of organizations that typically accompanies adoption of new technology" (Zach, 2016, p. 76). It maintains the focus on creating a system that integrates into existing Marine infantry structures without degradation to team performance.

2. Benefits of Individual SA Assessment to UTACC UxS Design

SA assessments provide a method for iteratively testing the effectiveness and performance of UxS "thinking." Evaluations of Marine thought processes are often subjective, but machine programming provides an opportunity to record and evaluate objective SA data. SA assessments should focus on those processes and correlations between situation elements and agent SA. Specific SA assessments should seek to map the interactions between agent perception and the particular schema used to build comprehension and projection in order to improve programming. With Marines, this is very hard to judge with complete certainty once the synthesis of more than one schema is involved. Until systems are ready to be field tested, UTACC can evaluate the SA capacity of UxS "brains" in a similar manner to Marine scenario training: presentation of situations and assessments of what the agent knows to look for. This focuses on the fundamental question of SA self-assessments: does the agent know what they do not know but should know?

3. Benefits of Team SA Assessment to UTACC UxS Design

The team SA assessment conducted by Sulistyawati et al. (2009) provides a repeatable methodology that would work well in evaluating Marine Corps infantry fire team SA, but it stops short of what UTACC requires. UTACC is design oriented, so the team design should focus on iterative assessments that first capture the team mechanisms of infantry fire teams then assess and improve Marine-machine team mechanisms. Specific focus should be applied to SA deltas—what is different between team members' SAs and why? This applies not just to perception but to comprehension and projection as well. If two team members have the same perception but reach different comprehension, there is still an identifiable breakdown of team SA. The intent is to improve UxS design to better support team SA, not to simply assess what a particular UxS does well. Team SA assessment should not leave the UxS out—it is just as important to assess the UxS's assessment of other team members' SA as it is to assess Marine assessments of the UxS's SA.

Assessments should evaluate the FTL from two levels of abstraction: team member and team leader. His individual responsibilities are no different in concept from the other members, but his role as the team leader adds additional responsibilities for all intrateam dynamics. Evaluations of the FTL's SA can give an overarching view of the success of team mechanisms at distributing SA throughout the team because the FTL is the central hub of the team. Analysis of the FTL's SA requirements about team performance of responsibilities adds an additional dimension to what team members need to know in order to accomplish their tasks.

With respect to team SA assessment, questions should focus on the following: what is the team SA breakdown and where, when, and why did it happen? A representative list of questions that would achieve this intent is included in Appendix F.

4. All-Marine Fire Team versus Marine-UxS Fire Team

Whatever the solution that UTACC designs, it will be different from a human Marine. This is a key concept central to useful evaluations: machines are likely to lose a contest of whether humans or robots are better at being a human Marine. Machines are purpose built and lack human adaptability. The intent is not to build a replacement Marine; it is to build a Marine-machine fire team that is at least as effective as current Marine fire teams. Assessments should evaluate UTACC designs on their impact to the fire team as a whole with the understanding that their individual capabilities may be significantly less than the Marine AR they are replacing. Above all, UxS impact on team SA should not be assessed in isolation; SA is meaningless when separated from a task, so all assessments should center on performance and effectiveness in accomplishing the task. Each task and situation are different, and the assessments are likely to find that Marine-machine teams achieve different results in different task situations. The roles and responsibilities of UxS within fire teams will have to be controlled during individual assessments, but experimentation with different roles and responsibilities should be attempted. One particular gain may be in offloading mundane cognitive responsibilities to the UxS in order to allow Marines to focus limited attention resources on more complex issues.

5. Differences between Marines and Machines

Humans tend to think in serial fashion, and the integration of machines into the infantry fire team could result in significant multitasking of those responsibilities assigned to the UxS. Robots could process multiple inputs simultaneously, as well as evaluate SA inputs across multiple zones of interest and levels of abstraction in parallel. They will, however, struggle with other things that humans do well. UxS may not understand levels of SA—they may have to be designed to instead mimic human levels of SA.

All-Marine fire team evaluations would provide a valuable baseline of team SA and the mechanisms used to achieve them. This would be useful, not only for comparison of UTACC progress, but also for seeking solutions when Marine-machine team SA breakdowns occur. Understanding how Marines overcome similar problems would provide insights into design solutions for Marine-machine teams. This will be more difficult to achieve if fire teams change organization and procedures significantly with the introduction of collaborative UxS.

6. Evaluation versus Comparison of Components and Designs

Assessments that involve comparisons between different UxS components and designs should be viewed critically. Knowing which of two poorly performing systems performed better will not in and of itself help UTACC designers. Decompositions of the two systems that determine *why* one system outperformed the other would be more useful. Comparisons are not inherently bad; subjective assessments about Marines' preferences for certain configurations or systems over others could highlight previously overlooked team performance issues in the design of UxS.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

This thesis serves as a jumping off point with respect to the importance of prioritizing SA as an overarching design requirement for UTACC. It also provides a bridge between previous work that utilized Coactive Design and future theses that could contribute to the understanding of SA in the Marine infantry and Marine-machine teaming environments.

1. SA Requirements Analysis for All Fire Team T&R Events

As previously discussed, the authors selected the "conduct fire and movement" T&R event as it forms the basis for numerous higher-level events. The remaining fire team T&R events, however, require analyses of interdependency. Marine infantry SMEs should be intimately involved in the process as their contributions to the detailed analysis should not be under-emphasized. Additionally, a background in SA would be extremely beneficial for the author or authors of this future research. Furthermore, the authors recommend that researchers leverage Endsley's work on SA requirements analysis and the infantry operating environment.

2. IA Tables

Once SA requirements analyses have been conducted for all fire team T&R events, IA tables should be developed for each event. While the SA requirements analyses are extremely useful for individual and team SA assessments, the specific value for UTACC is in the IA tables. Infantry SMEs should be used to review the interdependency assessments and OPD requirements to ensure completeness and accuracy. Due to the significant time investment involved in producing IA tables, the authors recommend focusing efforts on those T&R events that each iteration of UTACC UxS is expected to perform. Fortunately, many of the Level 1 SA requirements and OPD considerations repeat across multiple tasks and subtasks. The differences will be most prominent for Levels 2 and 3 SA interdependencies. The IA tables are finite snapshots of particular UxS capabilities in particular situations. The tables presented in this thesis used projections of what the authors assessed UxS performance capabilities currently are or could be in the near term. Specific systems may be more or less capable in specific areas than depicted, and IA tables will require revision to account for changes to UxS capabilities as designs change and programming improves.

3. Assessments for when UTACC Is Mature Enough

Full-scale SA assessments will require a complete and mature UTACC UxS in order to conduct a holistic evaluation, but iterative assessments could test specific components or programming. For example, only cameras and software are required to evaluate how well a UxS recognizes and processes enemy disposition information. Similarly, assessments can evaluate schemata associations by asking the UxS software to categorize new or combined situation schemata against pre-programmed schemata.

MCWL could conduct Marine-only SA assessments to generate baseline results for comparison to future Marine-machine assessments, but the need to control the situation environment presents a problem. Ideally, MCWL should conduct Marine-only SA assessments simultaneously with Marine-machine evaluations in order to better control the situation and environmental variables.

C. CHAPTER CONCLUSION AND SUMMARY

Developing a Marine-machine UxS that enhances fire team SA in the infantry operating environment is a significant undertaking. The heart of the problem lies in the common language and shared mental models that humans require in order to facilitate effective team SA. The SA requirements necessary to design such a system are not well codified and require comprehensive analysis. Coactive Design is an effective method to translate those SA requirements into design requirements for the UTACC program.

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APPENDIX A. INFANTRY BATTALION THROUGH INDIVIDUAL MARINE T&R EVENTS

Table 14. Infantry Battalion through Individual Marine T&R Events. Source: DON HQ USMC (2013).

EVENT CODE	E-CODED	EVENT	PAGE
		COMMAND AND CONTROL	
INF-C2-7001		Employ Command and Control (C2) Systems	4-4
INF-C2-7002		Integrate Command and Control (C2) Systems	4-6
INF-C2-7003	**YES**	Establish a Command Post (CP) (B)	4-7
INF-C2-7004	**YES**	Conduct Combat Operations Center (COC) Operations (B)	4-7
INF-C2-7005	**YES**	Conduct planning	4-9
INF-C2-7006	**YES**	Conduct assessment (D)	4-10
INF-C2-7007		Conduct Information Management (IM)	4-11
INF-C2-7009		Integrate Enabler Support	4-12
INF-C2-7010	**YES**	Execute Command and Control (C2) (B)	4-13
INF-C2-7011		Coordinate Force Deployment Planning & Execution (FDP&E)	4-14
INF-C2-7013		Integrate Marine Air Command and Control Support (MACCS)	4-15
		COMBAT SERVICE SUPPORT	
INF-CSS-7001		Conduct logistics planning (B)	4-16
INF-CSS-7002	**YES**	Conduct Combat Service Support (CSS) (B)	4-17
INF-CSS-7003		Process casualties (D)	4-18
INF-CSS-7004		Conduct detainee operations (D)	4-19
		FORCE PROTECTION	
INF-FP-7001	**YES**	Conduct force protection (D)	4-20
INF-FP-7002		Employ Operational Security (OPSEC) Measures	4-21
INF-FP-7004		Conduct Chemical, Biological, Radiological, Nuclear (CBRN) operations	4-22
		FIRE SUPPORT	
INF-FSPT-7001	**YES**	Conduct fire support planning (B)	4-23
INF-FSPT-7002	**YES**	Conduct fire support coordination (B)	4-24
INF-FSPT-7003		Conduct Decide, Detect, Deliver, Assess (D3A) targeting (B)	4-25
INF-FSPT-7004		Conduct Information Operations (IO)	4-26
INF-FSPT-7005		Integrate Electronic Warfare (EW)	4-27
		INTELLIGENCE	
INF-INT-7001	**YES**	Conduct functional intelligence	4-28
INF-INT-7002		Conduct Reconnaissance & Surveillance (R&S) Operations (B)	4-29
		MANEUVER	
INF-MAN-7001	**YES**	Conduct a ground attack (B,D)	4-31
INF-MAN-7002		Conduct a movement to contact (B,D)	4-34
INF-MAN-7003		Conduct a pursuit (B,D)	4-36
INF-MAN-7004		Conduct exploitation (B,D)	4-37
INF-MAN-7005		Conduct an armored/infantry operation (B,D)	4-38
INF-MAN-7006		Conduct a Helicopter/tilt-rotor assault (B,D)	4-39
INF-MAN-7007		Conduct a bypass operation (B)	4-41
INF-MAN-7101	**YES**	Conduct a position defense (B,D)	4-42
INF-MAN-7102		Conduct a mobile defense (B,D)	4-44
INF-MAN-7103		Conduct retrograde (B,D)	4-46
INF-MAN-7104		Conduct security operations (B)	4-48
INF-MAN-7201		Operate in an environment with an Improvised Explosive Device (IED) threat (D)	4-49
INF-MAN-7202		Conduct a mounted tactical road march (B,D)	4-50
INF-MAN-7203		Occupy an assembly area	4-52
INF-MAN-7204		Conduct a Relief In Place (RIP) (B)	4-53
INF-MAN-7205		Conduct a gap crossing (B)	4-54
INF-MAN-7206		Conduct passage of lines (D)	4-55
INF-MAN-7207		Conduct a linkup (D)	4-56
INF-MAN-7208		Conduct obstacle breaching (B,D)	4-57
INF-MAN-7210		Conduct reserve operations (B)	4-58
INF-MAN-7211		Conduct rear area operations	4-59
INF-MAN-7212		Conduct Route Reconnaissance and Clearance (R2C) operations (D)	4-60
INF-MAN-7213		Operate in a Chemical, Biological, Radiological, Nuclear (CBRN) environment	4-60
INF-MAN-7214		Employ Scout Snipers (D)	4-61
INF-MAN-7215		Control an area (B,D)	4-63
INF-MAN-7301		Conduct an amphibious assault (B,D)	4-63
INF-MAN-7302		Develop a landing plan (B)	4-64
INF-MAN-7303		Conduct an amphibious withdrawal (B,D)	4-66
INF-MAN-7304		Conduct an amphibious raid (B,D)	4-68
INF-MAN-7306	**YES**	Conduct an Amphibious Landing (B)	4-69
INF-MAN-7401	**YES**	Conduct Civil Military Operations (CMO) (B,D)	4-70
INF-MAN-7402		Restore civil security (B,D)	4-71
INF-MAN-7403		Support the establishment of civil control (B,D)	4-73
INF-MAN-7404		Support the restoration of essential services (B,D)	4-74
INF-MAN-7405		Support local governance (D)	4-75
INF-MAN-7406		Support economic development	4-76
INF-MAN-7408		Train & mentor foreign security forces (D)	4-77
		TRAINING	
INF-TRNG-7001		Manage Unit training and readiness	4-79

EVENT CODE	E-CODED	EVENT	PAGE
		COMMAND AND CONTROL	
INF-C2-6001		Employ Command and Control (C2) systems (D)	5-4
INF-C2-6002	**YES**	Conduct Company Combat Operations Center (CCOC) Operations (D)	5-5
INF-C2-6003	**YES**	Conduct planning (D)	5-6
INF-C2-6004	**YES**	Conduct assessment (D)	5-7
INF-C2-6005		Conduct Information Management (IM) (D)	5-8
INF-C2-6006		Integrate Enabler Support (D)	5-9
INF-C2-6007	**YES**	Execute Command and Control (C2) (D)	5-10
INF-C2-6008		Conduct Force Deployment Planning & Execution (FDP&E)	5-11
INF-C2-6009		Prepare for operations (D)	5-12
		COMBAT SERVICE SUPPORT	
INF-CSS-6001	**YES**	Conduct tactical logistics	5-12
INF-CSS-6002		Process casualties (D)	5-13
INF-CSS-6003		Process detainees (D)	5-14
INF-CSS-6004		Conduct resupply of the unit via aerial delivery	5-15
		FORCE PROTECTION	
INF-FP-6001	**YES**	Conduct force protection	5-16
INF-FP-6002		Employ Operational Security (OPSEC) Measures	5-17
INF-FP-6004		Conduct Chemical, Biological, Radiological, Nuclear (CBRN) operations	5-17
INF-FP-6005		Operate an Entry-Control Point (ECP) (D)	5-18
INF-FP-6006		Operate a Tactical Control Point (TCP) (D)	5-19
		FIRE SUPPORT	
INF-FSPT-6001	**YES**	Conduct fire support planning (B)	5-19
INF-FSPT-6002	**YES**	Conduct fire support coordination (B)	5-20
INF-FSPT-6003		Conduct Decide, Detect, Deliver, Assess (D3A) targeting (B)	5-21
INF-FSPT-6004		Conduct Information Operations (IO) (D)	5-22
INF-FSPT-6005		Integrate Electronic Warfare (EW)	5-23
INF-FSPT-6006	**YES**	Conduct Fire Support Team (FiST) operations (B,D)	5-24
		INTELLIGENCE	
INF-INT-6001	**YES**	Provide intelligence support to company COC operations (D)	5-26
		MANEUVER	
INF-MAN-6001	**YES**	Conduct a ground attack (B,D)	5-27
INF-MAN-6002		Conduct a movement to contact (B,D)	5-30
INF-MAN-6003	**YES**	Conduct helicopter-borne/tiltroter-borne operations	5-32
INF-MAN-6004	**YES**	Conduct a raid (B,D)	5-34
INF-MAN-6005	**YES**	Integrate armor	5-36
INF-MAN-6006		Clear an area (D)	5-37
INF-MAN-6101	**YES**	Conduct a position defense (B,D)	5-38
INF-MAN-6102		Conduct a mobile defense (B,D)	5-41
INF-MAN-6103		Conduct retrograde (B)	5-42
INF-MAN-6201		Operate in an environment with an Improvised Explosive Device (IED) threat (D)	5-44
INF-MAN-6202		Conduct a tactical march (B,D)	5-45
INF-MAN-6203		Occupy an assembly area	5-46
INF-MAN-6204		Conduct a Relief in Place (RIP) (B,D)	5-46
INF-MAN-6205		Conduct a gap crossing (B)	5-48
INF-MAN-6206		Conduct passage of lines (D)	5-49
INF-MAN-6207		Conduct a linkup (B,D)	5-50
INF-MAN-6208		Conduct obstacle breaching (B,D)	5-51
INF-MAN-6209		Consolidate and reorganize	5-52
INF-MAN-6210		Conduct reserve operations (B)	5-53
INF-MAN-6211		Support by fire/overwatch (D)	5-54
INF-MAN-6212	**YES**	Conduct patrolling operations (D)	5-55
INF-MAN-6213		Occupy a patrol base	5-56
INF-MAN-6214		Conduct a screen (B,D)	5-57
INF-MAN-6215		Participate in guard operations (B,D)	5-58
INF-MAN-6216		Conduct a cordon and search (B,D)	5-59
INF-MAN-6217		Integrate Scout Snipers (B)	5-60
INF-MAN-6301	**YES**	Participate in an amphibious assault (D)	5-61
INF-MAN-6302		Conduct an amphibious raid (D)	5-62
INF-MAN-6401	**YES**	Conduct Civil Military Operations (CMO) (D)	5-63
INF-MAN-6402		Support the establishment of civil control (D)	5-64
INF-MAN-6403		Support the restoration of essential services (D)	5-65
INF-MAN-6404		Support local governance	5-67
INF-MAN-6405		Support economic development (D)	5-68
INF-MAN-6406		Restore civil security (D)	5-69
INF-MAN-6407		Train and mentor foreign personnel (D)	5-70
		TRAINING	
INF-TRNG-6001		Manage Unit training and readiness (C,D)	5-71

EVENT CODE	EVENT	PAGE
	1000-LEVEL	
	COMBAT HUNTER	
0300-CMBH-1001	Conduct observation (D)	8-6
0300-CMBH-1002	Identify anomalies (D)	8-7
0300-CMBH-1003	Identify spoor (D)	8-8
0300-CMBH-1004	Explain the decision cycle (OODA) process	8-9
	COMMUNICATIONS	
0300-COMM-1001	Communicate using hand and arm signals	8-10
0300-COMM-1002	Communicate using limited visibility signals	8-11
0300-COMM-1003	Communicate using wired communications	8-12
0300-COMM-1005	Operate a VHF field radio	8-12
0300-COMM-1006	Submit a message	8-13
	COMBAT CONDITIONING	
0300-COND-1001	March under an approach march load	8-13
	DEFENSE	
0300-DEF-1001	Construct a two-man fighting hole	8-14
0300-DEF-1002	Construct a hasty fighting position	8-15
0300-DEF-1003	Defend a position (B,D)	8-15
	DEMOLITIONS	
0300-DEMO-1002	Engage targets with the M67 fragmentation grenade	8-16
0300-DEMO-1003	Emplace an M18A1 Claymore mine	8-17
	M16	
0300-M16-1005	Zero a Rifle Combat Optic (RCO) to a service rifle (D)	8-18
0300-M16-1007	Zero a Mini Integrated Pointer Illuminator Module (MIPIM) to a service rifle/Infantry Automatic Rifle (IAR) (D)	8-19
0300-M16-1010	Execute Intermediate Combat Rifle Marksmanship Table 3A Short Range Day (B,D)	8-20
0300-M16-1011	Execute Intermediate Combat Rifle Marksmanship Table 3B Short Range Night (D)	8-21
0300-M16-1012	Execute Intermediate Combat Rifle Marksmanship Table 3C Unknown Distance Day (B,D)	8-22
0300-M16-1013	Execute Intermediate Combat Rifle Marksmanship Table 3D Known Distance Night (D)	8-23
0300-M16-1014	Execute Advanced Combat Rifle Marksmanship Table 4A Short Range Day (B,D)	8-24
0300-M16-1015	Execute Advanced Combat Rifle Marksmanship Table 4B Short Range Night (D)	8-25
0300-M16-1016	Execute Advanced Combat Rifle Marksmanship Table 4C Unknown Distance Day (B,D)	8-26

0300-M16-1017	Execute Advanced Combat Rifle Marksmanship Table 4D Unknown Distance Night (D)	8-27
	M203	
0300-M203-1001	Maintain an M203 grenade launcher	8-28
0300-M203-1002	Perform weapons handling procedures for the M203 grenade launcher (B)	8-28
0300-M203-1003	Perform misfire procedures for an M203 grenade launcher (B)	8-29
0300-M203-1004	Zero a M203 grenade launcher (B,D)	8-30
0300-M203-1005	Engage targets with a grenade launcher (B,D)	8-31
	MEDICAL	
0300-MED-1001	Perform tactical field care on a casualty	8-32
	MOUT	
0300-MOUT-1001	Perform individual movement in an urban environment (B,D)	8-32
0300-MOUT-1002	Perform individual actions while clearing a room (B,D)	8-33
	OFFENSE	
0300-OFF-1001	Perform actions in a hasty firing position (B)	8-34
	OPTICS	
0300-OPTS-1001	Utilize limited visibility devices (B)	8-34
	PATROLLING	
0300-PAT-1001	Determine the error in a lensatic compass	8-35
0300-PAT-1002	Develop a route card	8-36
0300-PAT-1003	Navigate with a map and compass (D)	8-37
0300-PAT-1004	Prepare for combat	8-37
0300-PAT-1005	Perform individual movement techniques (B,D)	8-38
0300-PAT-1006	Handle detainees (D)	8-39
0300-PAT-1007	Perform individual actions in passage of lines (B,D)	8-39
0300-PAT-1008	Perform individual actions in a patrol (B,D)	8-40
0300-PAT-1009	Perform immediate actions upon contact with the enemy (D)	8-41
0300-PAT-1010	Perform individual actions from a vehicle (B,D)	8-42
0300-PAT-1011	Visually identify Improvised Explosive Device (IED) (B,D)	8-43
0300-PAT-1012	React to an Improvised Explosive Device (IED) (B,D)	8-43
	WEAPONS	
0300-WPNS-1001	Inspect the AT-4 light anti-armor weapon (B)	8-44
0300-WPNS-1002	Engage target with an AT-4 light anti-armor weapon (B,D)	8-45
0300-WPNS-1003	Perform misfire procedures for an AT-4 light anti-armor weapon (B)	8-46
0300-WPNS-1004	Engage targets with an M72 series Weapon (D)	8-47
0300-WPNS-1005	Perform misfire procedures for an M72 series weapon	8-48
0300-WPNS-1007	Inspect the M72 series Weapon	8-49
	2000 LEVEL EVENTS	
	CBRN	

0300-CBRN-2001	Operate in a Chemical, Biological, Radiological, Nuclear (CBRN) Environment (B,D)	8-50
COMBAT HUNTER		
0300-CMBH-2001	Analyze spoor (D)	8-50
0300-CMBH-2002	Perform individual actions as a tracker (D)	8-51
0300-CMBH-2003	Develop an integrated observation plan	8-52
0300-CMBH-2004	Profile an anomaly (D)	8-53
0300-CMBH-2005	Lead a combat tracking team (D)	8-54
0300-CMBH-2007	Integrate combat policing	8-54
0300-CMBH-2009	Utilize tactical questioning	8-55
COMMUNICATIONS		
0300-COMM-2001	Submit a helicopter landing zone brief (B)	8-56
0300-COMM-2002	Submit a shell report	8-57
0300-COMM-2003	Submit a casualty report (B)	8-57
0300-COMM-2004	Operate a UHF field radio	8-58
0300-COMM-2005	Operate Satellite Communication (SATCOM) devices	8-59
0300-COMM-2006	Employ a field expedient antenna	8-60
0300-COMM-2007	Communicate using squad wireless communications	8-60
DEMOLITIONS		
0300-DEMO-2001	Probe for a mine	8-61
0300-DEMO-2002	Qualify on the grenade distance and accuracy course	8-61
FIRE SUPPORT		
0300-FSPT-2001	Plan supporting arms (B)	8-62
0300-FSPT-2002	Call for indirect fire using the grid method (B)	8-63
0300-FSPT-2003	Call for indirect fire using the polar method (B)	8-64
0300-FSPT-2004	Call for indirect fire using the shift from a known point method (B)	8-66
0300-FSPT-2005	Act as an observer for Close Air Support (CAS) (B)	8-67
INFANTRY SMALL UNIT LEADERSHIP		
0300-ISUL-2501	Lead a squad (B,D)	8-68
M16		
0300-M16-2001	Perform weapons handling procedures with a service rifle/Infantry Automatic Rifle (IAR) (B)	8-69
0300-M16-2002	Maintain a service rifle	8-70
0300-M16-2003	Perform corrective action with a service rifle (B,D)	8-71
0300-M16-2004	Zero Iron Sights to a service rifle (D)	8-71
0300-M16-2005	Engage Moving Threats (B)	8-72
M9		
0300-M9-2001	Perform weapons handling procedures with the service pistol (B)	8-73
0300-M9-2002	Perform operator maintenance for the service pistol	8-74
0300-M9-2003	Engage targets with the service pistol (B)	8-75
0300-M9-2004	Qualify with the service pistol (B)	8-75
MOBILITY		
0300-MOBL-2001	Lead a team/squad in convoy/motorized operations	8-76
0300-MOBL-2003	Conduct mounted land navigation	8-77
PATROLLING		
0300-PAT-2001	Develop a warning order	8-78
0300-PAT-2002	Write a combat order	8-78
0300-PAT-2003	Issue a combat order	8-79
0300-PAT-2004	Develop a map overlay	8-80
0300-PAT-2005	Select a route utilizing a topographical map	8-81
0300-PAT-2006	Navigate with a Global Positioning System (GPS)(D)	8-81
0300-PAT-2007	Lead a unit in reaction to a detonated Improvised Explosive Device (IED)(B,D)	8-82
0300-PAT-2008	Lead a unit in reaction to a undetonated Improvised Explosive Device (IED) (B,D)	8-83
TRAINING		
0300-TRNG-2001	Lead a debrief (B)	8-84
0300-TRNG-2002	Construct an Operational Risk Management (ORM) assessment	8-84
0300-TRNG-2003	Conduct small unit training (B,C,D)	8-85
TACTICAL VEHICLE		
0300-TVEH-2001	Establish a load plan for a tactical vehicle (B)	8-86
0300-TVEH-2002	Prepare an immobilized vehicle for towing operations from the front	8-86
0300-TVEH-2003	Perform hydraulic winch operations with a tactical vehicle	8-87
0300-TVEH-2004	Conduct non-standard recovery methods for a tactical vehicle	8-88
0300-TVEH-2005	Maneuver a tactical vehicle during off-road operations (B)	8-88
0300-TVEH-2006	Camouflage a tactical vehicle	8-89
0300-TVEH-2009	Communicate using hand and arm signals	8-89
0300-TVEH-2010	Perform tactical vehicle maneuvers (B)	8-90
0300-TVEH-2015	Communicate using organic tactical vehicle radio communications equipment (B)	8-91
0300-TVEH-2017	Provide security during vehicle security halts (B)	8-92
WEAPONS		
0300-WPNS-2001	Zero the Laser Boresight	8-92
0300-WPNS-2002	Boresight a weapon using the Laser Boresight System	8-93
0300-WPNS-2003	Defeat an enemy in hand to hand combat	8-94
0300-WPNS-2006	Handle small arms threat weapons (B)	8-94

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APPENDIX B. INFANTRY MOUT SA ELEMENTS

Table 15. Infantry MOUT SA Elements. Source: Matthews et al. (2004.)

Mission Elements	*Level 1 SA*	*Level 2 SA*	*Level 3 SA*
Threat			
	Enemy disposition	Enemy fields of observation	Projected enemy actions
	Enemy location	Enemy fields of fire	Projected likelihood of enemy attack
	Enemy dispersion	Enemy strengths/weaknesses	Projected likelihood of enemy contact
	Enemy numbers	Enemy exposure areas	Projected impact of threat on mission accomplishment
	Enemy weapons	Enemy vulnerabilities	Projected impact of avoiding threat on mission accomplishment
	Enemy ammunition	Level of threat	Projected forces/actions required to neutralize threat
	Enemy supply level	Immediacy of threat	
	Enemy intent	Severity of threat	
	Enemy objective	Ability to avoid threat	
	Enemy composition	Strategic significance of enemy heavy weapons	
	Enemy unit type	Strategic significance of enemy disposition	
	Enemy equipment	Impact of threat on mission	
	Enemy experience level	Enemy expectations	
	Enemy morale/ commitment	Confidence level in threat information	
	Enemy capabilities/ skills/training	Sensor coverage areas	
	Enemy recent actions		
	Enemy vehicles		
	Enemy patterns of movement/actions		
	Enemy supply locations		
	Enemy lines of supply		
	Enemy movement of weapons		
	Enemy security/patrols formation & schedule		
	Enemy LP/OP locations		
	Enemy fires		
	Enemy heavy weapons locations		
	Enemy fires locations		
	Enemy locus of fires		
	Enemy accuracy of fires		
	Enemy lines/means of communication		
	Enemy center of gravity		

Mission Elements	*Level 1 SA*	*Level 2 SA*	*Level 3 SA*
	Enemy psychology		
	Enemy doctrine		
	Enemy past behavior		
	Enemy beliefs		
	Enemy reinforcement availability		
Friendly			
	Friendly disposition	Friendly fields of observation	Projected likelihood of fratricide
	Friendly location	Friendly fields of fire	Planned/projected friendly action locations
	Friendly dispersion	Friendly strengths/ weaknesses	Projected ability to avoid fires
	Friendly numbers	Friendly exposure areas	Projected time to obtain cover/ concealment
	Friendly weapons	Friendly vulnerabilities	Projected casualties
	Friendly ammunition		Projected troop fatigue
	Friendly supply level		Projected ability of individual to perform tasks
	Friendly composition		Projected effect of moving casualties
	Friendly unit type		Projected time required for evacuation of casualties
	Friendly equipment		
	Friendly experience level		
	Friendly morale/commitment		
	Friendly capabilities/skills/ training		
	Friendly recent actions		
	Friendly vehicles		
	Friendly psychology		
	Friendly doctrine		
	Friendly past behavior		
	Friendly character/discipline		
	Friendly fatigue level		
	Friendly movements		
	Friendly objective		
	Number/severity of casualties		
	Medical personnel availability		
	Medical supply level		
Civilian			
	Civilian location	Level of threat from civilians	Projected civilian casualties
	Civilian numbers	Sensitive areas	Projected effect of actions on civilian behavior, escalation
	Civilian level of organization		

Mission Elements	*Level 1 SA*	*Level 2 SA*	*Level 3 SA*
	Civilian mood of crowd		
	Civilian religious/political beliefs		
	Civilian agitators present		
	Civilian threatening actions		
	Civilian morale/commitment		
	Civilian training/skills		
	Civilian intent		
	Civilian weapons		
Supplies			
	Supply access points		Projected usage rate of supplies
	Location/quantity of water		Projected requirements for additional supplies
	Location/quantity of food		
	Location/quantity of ammunition		
Mission			
	Location of objective	Asset usage rate required for mission	Projected cost of planned attack (time/troops)
	Areas of operation/boundaries	Time to obtain assets for mission	Projected ammo/supplies required for actions
	Commander's intent	Lead squad at objective	Projected ability to carry out actions
	Mission objective	Assets needed for mission completion	Projected force required for mission
	Course of action (COA)	Weapons needed for mission completion	Projected impact of fires on mission
	Availability of fires	Priority of fires	Projected effect of fires on enemy behavior
	Availability of combat multipliers		
	Availability of reinforcements	Mission task completion status	
	Asset availability/location/type	Time available for task completion	
	Individual taskings for mission	Task criticality	
	Rules of engagement	Deviations from COA	
		Unexpected events	
		Battle damage assessment	
Terrain			
	Type of terrain (hilly, flat, mountainous, urban)	Available ingress routes	Projected time on route
	Terrain conditions (rubble, mud)	Available egress routes	Projected entry time
	Railroad tracks	Trafficability of routes	Projected ability to detect enemy
	Terrain features (vegetation, obstacles, buildings)	Level of exposure on route	Projected ability to be detected

Mission Elements	*Level 1 SA*	*Level 2 SA*	*Level 3 SA*
	Buildings	Areas of cover	Projected likelihood of enemy encounter on routes
	Building type/usage	Areas of concealment	Projected ability to avoid fires along route
	Building construction	Difficulty of route	Projected time to achieve cover/concealment along route
	Size/type of rooms	Number of key points on route	
	Activities/personnel in adjacent rooms	Mental requirements of route	
	Rooms cleared	Speed of movement along route	
	Smoke/NBC in rooms	Potential fields of fire	
	Fortifications/obstacles	Potential fields of observation	
	Floor plan	Strategic points	
	Threats/weapons in rooms	Funnel areas	
	Corridors/stairwells		
	Entry points (mechanical, explosive)		
	Sewer system		
	Roads		
	Bodies of water		
Weapons/fire effects	Areas/timing/type of planned fires	Priority of fires	Projected enemy breech points
	Areas/timing/type of current fires	Areas/severity of damage	Projected areas of fire
	Direction of fires (other friendlies)	Priority of indirect fires	Projected enemy areas of approach
	Targets designated for fires	Enemy expectations of fires	Projected effect of fires on enemy
	Availability of indirect fires	Priority of targets	Projected effect of smoke on own/enemy visibility
	Availability of combat multipliers	Assignment of targets	Projected dispersion of smoke
		Impact of weather on smoke	Projected outcome of engagement
		Holes in FOF/FOO	
		Ability of enemy to reposition troops	
Communications	Information/orders given	Areas of poor communications	Projected areas of poor communication

Mission Elements	*Level 1 SA*	*Level 2 SA*	*Level 3 SA*
	Information received	Need for stealth	
	Comm channel/reliability	Need to report information	
	Equipment status		
	Backup comm availability		
	Frequency/call signs of supporting units		
Weather			
	Temperature		
	Precipitation (snow, rain)		
	Wind		
	Visibility		
	Ambient noise		
	Time of day/level of light		

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APPENDIX C. CONDUCT FIRE AND MOVEMENT T&R EVENT INF-MAN-3001

INF-MAN-3001: Conduct fire and movement (B,D)

SUPPORTED MET(S): 2

EVALUATION-CODED: NO   **SUSTAINMENT INTERVAL:** 3 months

CONDITION: Given a unit, an order, and while or while not serving as the base unit as part of a larger unit or independently.

STANDARD: To accomplish the mission and meet the commander's intent.

EVENT COMPONENTS:
1. Suppress the enemy (S).
2. Assess effects of fires (A).
3. Adjust fires as necessary.
4. Identify next covered position.
5. Move to next covered position under the cover of suppression(M).
6. Identify your target and continue suppression to allow buddy to move to next covered position.
7. Repeat steps 1-5 until the objective is reached.
8. Execute actions on the objective (K).
9. Consolidate.

PREREQUISITE EVENTS:

0300-M16-1005	0300-M16-1007	0300-M16-1010
0300-M16-1011	0300-M16-1012	0300-M16-1013
0300-M16-1014	0300-M16-1015	0300-M16-1016
0300-M16-1017	0300-MED-1001	0300-MOUT-1001
0300-MOUT-1002	0300-OPTS-1001	0300-PAT-1004
0300-PAT-1005	0300-PAT-1008	0300-PAT-1009
0311-TRNG-2001	0311-TRNG-2002	

REFERENCES:
1. FM 21-75 Combat Skills of the Soldier
2. MCWP 3-11.1 Marine Rifle Company/ Platoon
3. MCWP 3-11.2 w ch1 Marine Rifle Squad

SUPPORT REQUIREMENTS:

ORDNANCE:

DODIC	Quantity
A059 Cartridge, 5.56mm Ball M855 10/Clip	40 rounds per Marine
L594 Simulator, Projectile Ground Burst M	1 projectiles per Team

RANGE/TRAINING AREA:
Facility Code 17410 Maneuver/Training Area, Light Forces
Facility Code 17430 Impact Area Dudded
Facility Code 17730 Fire And Movement Range
Facility Code 17750 Infantry Squad Battle Course

OTHER SUPPORT REQUIREMENTS: This event can be trained/augmented through the use of the following enablers:
LIVE - ITESS, TVCS, ITT, SESAMS, TGTS, BES
VIRTUAL/CONSTRUCTIVE - CCS DVTE (VBS2)

MISCELLANEOUS:

ADMINISTRATIVE INSTRUCTIONS: Considerations, means of movement include unit, buddy, and individual. The event may also be used for cover and movement when there is no immediate enemy threat. A leader issues the ADDRAC in support of this event.

Figure 17. Conduct Fire and Movement T&R Event INF-MAN-3001. Source: DON HQ USMC (2013).

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APPENDIX D. CONDUCT GROUND ATTACK T&R EVENT INF-MAN-4001

INF-MAN-4001: Conduct a ground attack (B,D)

SUPPORTED MET(S): 1, 2

EVALUATION-CODED: NO **SUSTAINMENT INTERVAL**: 3 months

CONDITION: Given a unit, attachments, an order, while motorized, mechanized, or dismounted, and operating in the full range of environmental conditions, during daylight and limited visibility.

STANDARD: To accomplish the mission and meet commander's intent.

EVENT COMPONENTS:
1. Conduct METT-T.
2. Task organize.
3. Issue a warning order.
4. Supervise pre combat checks.
5. Conduct leaders reconnaissance.
6. Integrate fires.
7. Coordinate logistics.
8. Complete the plan.
9. Issue order.
10. Lead pre combat inspections, rehearsals, rehearsal of concepts, and backbriefs.
11. Move to attack position.
12. Establish priority of work.
13. Employ supporting arms as required.
14. Cross the line of departure.
15. Breach obstacles as necessary.
16. Establish support by fire position(s).
17. Move through assault position.
18. Shift or cease supporting fires as required.
19. Conduct assault, using hand to hand combat as required.
20. Establish security.
21. Conduct information exploitation of the objective area.
22. Report to higher.
23. Plan for follow on actions.

REFERENCES:
1. MCRP 3-02B Marine Corps Martial Arts
2. MCWP 3-11.2 w ch1 Marine Rifle Squad

SUPPORT REQUIREMENTS:

ORDNANCE:

DODIC	Quantity
A059 Cartridge, 5.56mm Ball M855 10/Clip	100 rounds per Marine
L594 Simulator, Projectile Ground Burst M	1 projectiles per squad

RANGE/TRAINING AREA:
Facility Code 17410 Maneuver/Training Area, Light Forces
Facility Code 17430 Impact Area Dudded
Facility Code 17581 Machine Gun Field Fire Range
Facility Code 17631 Light Antiarmor Weapons Range Live
Facility Code 17670 Mortar Range
Facility Code 17750 Infantry Squad Battle Course

OTHER SUPPORT REQUIREMENTS: This event can be trained/augmented through the use of the following enablers:
LIVE - ITESS, TVCS, IIT, SESAMS, TGTS, BES
VIRTUAL/CONSTRUCTIVE - CCS, DVTE (VBS2)

MISCELLANEOUS:

ADMINISTRATIVE INSTRUCTIONS: Range must support all platoon weapons and attached weapons, to include dud-producing ordnance and overhead fires. TACTICAL CONSIDERATIONS: Actions on the objective may include repelling an enemy counterattack, pursuit of enemy by fire, etc. mech/tank considerations, dismount considerations, this event includes frontal and flanking attacks/ supported and unsupported, fire and movement and fire and maneuver. A leader issues the ADDRAC in support of this event.

Figure 18. Conduct Ground Attack T&R Event INF-MAN-4001. Source: DON HQ USMC (2013).

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APPENDIX E. FIRE AND MOVEMENT IA TABLE

Table 16. Fire and Movement IA Table

"Elements or individuals alternate the firing and movement" -- Subtasks A.1 & A.3 are conducted by the suppressor, while subtasks A.2, A.4, and A.5 are conducted by the mover. At subtask A.6, the elements/individuals switch roles, with the mover assuming suppression, and the prior suppressor preparing to move. Subtasks A.8 and A.9 are conducted by every element/individual simultaneously.

		Functional actions to accomplish subtask	METT-TSL (Mission, Enemy, Terrain & weather, Troops & fire support available, Time available, Space, Logistics)	Why is the requirement important (i.e., what comprehension can be gained from it?)	Present configuration -Fire team leader (FTL), Automatic rifleman (AR), Assistant automatic rifleman (AAR), Rifleman (RIF) -Actions performed by AR, supported by FTL, AAR, RIF				UTACC: -Fire team leader (FTL), Unmanned System (UxS), Assistant automatic rifleman (AAR), Rifleman (RIF) -Actions performed by UxS, supported by FTL, AAR, RIF				Mechanisms, interface design elements, etc. that meet the Observability, Predictability, Directability requirements synthesized through the analysis of the interdependent teaming role alternatives.
Tasks	**Subtasks and Description**	**Capacities**	**Level 1 SA requirements (METT-TSL)**	**SA requirements justification**	**FTL**	**AR**	**AAR**	**RIF**	**FTL**	**UxS**	**AAR**	**RIF**	**OPD/common ground/shared mental model requirements & comments**
(A) INF-MAN-3001 Conduct fire and movement. Fire and Movement is a technique of advance in which elements provide their own suppression and move by bounds. Elements and individuals alternate the firing and moving so that movement is always covered by fire, and the assault's momentum is retained.	(A.1) Suppress the enemy. Suppress is an enemy-oriented tactical mission task that results in the temporary degradation of the performance of a force or weapon system below the level needed to accomplish the mission. "Fore" position 1) engages the enemy and 2) covers sector (if no enemy present).	-Aim weapon -Fire weapon	(A.1.M.1) Mission objective	Context: what is the larger mission objective and how does suppression support mission objective? At minimum, FT must understand the next higher level (squad) task.									Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc.). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.1.M.2) Location of objective	Where is the objective in relation to suppression?									Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.1.M.3) Commander's intent	Context: why conduct this mission?									Machines may never understand this, or at least take a long time
			(A.1.M.4) Course of action / scheme of maneuver	Context: how does this task fit into scheme of maneuver?									Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (e.g., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.1.M.5) Priority of targets	Which types or specific targets are high value/payoff? If multiple targets present themselves, which should be engaged first? (Automatic gunners would typically focus on enemy automatic weapons over riflemen).									Directability: FTL needs capability to communicate target priorities to UxS. Observability: FTL needs capability to confirm UxS receipt of priorities. Predictability: Confirmed when UxS selects targets based on priorities. Achieved through training/experience with dynamic targets of varying priorities. Doctrinal for human AR. Current UxS could be programmed with priority targets but may struggle with application during execution. If machine can identify and distinguish targets by function/capability, it could execute this task with less or without assistance. Machine learning can overcome ability to identify enemy uniforms, vehicles, weapon systems visually/aurally. If machine could assess priority targets during execution and had access to distributed target data or camera feeds from other team members, could dramatically assist with assessing priority targets based on larger picture of the whole team.
			(A.1.M.6) Assignment of targets	Which targets did the FTL assign to the AR? Which targets are assigned to other FT members?									Directability: FTL needs capability to assign targets to UxS. Observability: FTL confirms receipt of target assignment by observing UxS fires - no different than with Marine. Predictability: Built through training and experience of target assignment & resultant actions. UxS should expect target assignments from FTL & needs to monitor FTL for assignments/updates during actions. If machine could process enemy targets, friendly locations, boundaries, COAs, etc. then machine may be able to optimize target assignments and feed info to other members. If UxS is currently incapable of identifying targets and

													implementing target assignments independently, a "gun buddy" UxS that follows a particular Marine and shoots what that Marine shoots may achieve intermediate progress (could be conducting machine learning for future capability at same time). Gun buddy UxS could feed Marine information from its sensors through various heads up interfaces that could support a hybrid Marine/machine buddy team that optimizes combination of robotic gains with Marine cognition and decision-making.
			(A.1.E.1) Enemy disposition (location, dispersion, numbers, weapons)	What does the enemy footprint look like, and what part of the enemy is the FT facing?									Directability: FT members need capability to communicate enemy disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Utilize ADDRAC, SALUTE, DRAW-D, EMLCOA, and EMDCOA etc. to standardize information. Depends on UxS sensor capability to perceive & processing power to comprehend targeting info from sensor feeds. Machine learning can overcome inability to identify enemy uniforms, vehicles, weapon systems visually/aurally. UxS may be more capable than Marines at identifying enemy disposition info based on time limited or partial observations of enemies. If all Marines had cameras, UxS could process distributed enemy disposition data and communicate it to all FT members.
			(A.1.TW.1) Type of terrain (hilly, flat, mountainous, urban)	Terrain type impacts rate of movement, visibility, fire control, and tactics.									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
			(A.1.TW.2) Terrain features (obstacles, enemy cover)	Terrain features affect fields of observation, avenues of approach, rate of movement, and available cover.									
			(A.1.TFS.1) Friendly disposition	It is a team task. Must be able to know position relative to FT members and adjacent/higher units.									Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
			(A.1.TFS.2) Friendly movement (in relation to suppressive fires)	Suppression has a purpose. Here it is to allow other FT members to move to next covered position. Suppression be focused on enemy targets that would interfere with that movement.									
			(A.1.TFS.3) Areas/timing/type of planned fires	What is the overall fires plan? Are any other planned fires going to achieve FT-specific suppression needs? How does this suppression fit into overall fires plan?									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: FTL needs capability to confirm UxS receipt of fires plan (ex: "Robot, what is your part of the fires plan?"). Predictability: UxS should have selectable permissions on starting/stopping fire (wait for a Marine to shoot first, cease fire if Marines cease fire, execute fires on order/timing/event, etc.). FTL must assign for UxS (significant potential for interface drain on SA in combat situation). Ideal UxS could interpret aural and visual commands/signals just like Marines. Robot can help FT members keep track of planned fires during execution. Robot could also be central hub for fires alerts coming to team in execution.
			(A.1.TFS.4) Areas/timing/type of current fires	What fires are actually occurring? Is necessary suppression being achieved by other fires? Is any adjacent/higher suppression not occurring as planned and does it affect FT suppression?									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e. RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (e.g., if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression).

			(A.1.TFS.5) Direction of fires (other friendlies)	Adjacent fires may indicate unseen targets. Fire and movement suppression is an alternating task between buddies or buddy pairs - if assuming suppression from prior FT member, what were they suppressing? That is probably what the AR/UxS should suppress.	Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are shooting IOT not interrupt their firing.
			(A.1.TA.2) Planned rate of movement	Interdependence between suppressor and mover	Directability: FTL needs capability to communicate planned rates of movement to UxS. FTL needs capability to order specific rates of movement for UxS. Observability: FTL needs capability to query UxS ability to achieve planned rates of movement. Predictability: UxS needs library of UxS and Marine rates of movement across varying terrain. UxS can assist with countdowns until clear, expected timing of suppression for movement rates and distances, and movement planning to meet time constraints.
			(A.1.S.1) Areas of operation/boundaries & fire support control measures	Context: how do FT & task fit into and affect larger/adjacent units & tasks? Must adhere to boundaries during task & subtask.	Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
			(A.1.L.1) Ammunition level	Ammunition level affects rate/volume of fire, especially when cross-referenced with distance to objective and rate of movement.	Directability: FTL needs capability to dictate ammunition conservation. Observability: FTL needs capability to observe UxS ammunition level. Utilize standard prowords "Shotgun," "Winchester," etc. to indicate particular ammunition states Predictability: FTL needs to capability to select actions/settings based on ammunition level (ex: at "Shotgun" request resupply & at "Winchester" move to AAR for reload assistance). If machine could track team's ammunition and alert members when to change mags before certain pushes, etc. They can also alert logistics quickly and automatically that team needs resupply.
	(A.2) Assess effects of fires. Marine in the "Aft" position 1) assesses the effects of his buddy's suppression before moving 2) looks to unit leader then buddy 3) identifies micro terrain 4) prepares a rocket/hand grenade 5) employs M203 6) reloads weapon 7) initiates the next buddy rush. ****This subtask is critical because robot is valuable asset. Needs to be able to move at right times so it doesn't get shot up immediately.		(A.2.M.1) Mission objective	Context: what is the larger mission objective and how does suppression support mission objective? At minimum, FT must understand the next higher level (squad) task.	Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc.). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.2.M.2) Location of objective	Where is the objective in relation to suppression?	Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.2.M.3) Commander's intent	Context: why conduct this mission?	Machines may never understand this, or at least take a long time
			(A.2.M.4) Course of action / scheme of maneuver	Context: how does this task fit into scheme of maneuver?	Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.

			(A.2.M.5) Priority of targets	Is suppressor adhering to priority of targets?									Directability: FTL needs capability to communicate target priorities to UxS. Observability: FTL needs capability to confirm UxS receipt of priorities. Predictability: Confirmed when UxS selects targets based on priorities. Achieved through training/experience with dynamic targets of varying priorities. Doctrinal for human AR. Current UxS could be programmed with priority targets but may struggle with application during execution. If machine can identify and distinguish targets by function/capability, it could execute this task with less or without assistance. Machine learning can overcome ability to identify enemy uniforms, vehicles, weapon systems visually/aurally. If machine could assess priority targets during execution and had access to distributed target data or camera feeds from other team members, could dramatically assist with assessing priority targets based on larger picture of the whole team.
			(A.2.M.6) Assignment of targets	Is suppressor adhering to assignment of targets?									Directability: FTL needs capability to assign targets to UxS. Observability: FTL confirms receipt of target assignment by observing UxS fires - no different than with Marine. Predictability: Built through training and experience of target assignment & resultant actions. UxS should expect target assignments from FTL & needs to monitor FTL for assignments/updates during actions. If machine could process enemy targets, friendly locations, boundaries, COAs, etc. then machine may be able to optimize target assignments and feed info to other members. If UxS is currently incapable of identifying targets and implementing target assignments independently, a "gun buddy" UxS that follows a particular Marine and shoots what that Marine shoots may achieve intermediate progress (could be conducting machine learning for future capability at same time). Gun buddy UxS could feed Marine information from its sensors through various heads up interfaces that could support a hybrid Marine/machine buddy team that optimizes combination of robotic gains with Marine cognition and decision-making.
			(A.2.E.1) Enemy disposition (location, dispersion, numbers, weapons)	Need to know where enemy are located in order to judge suppression effectiveness.									Directability: FT members need capability to communicate enemy disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Utilize ADDRAC, SALUTE, DRAW-D, EMLCOA, and EMDCOA etc. to standardize information. Depends on UxS sensor capability to perceive & processing power to comprehend targeting info from sensor feeds. Machine learning can overcome inability to identify enemy uniforms, vehicles, weapon systems visually/aurally. UxS may be more capable than Marines at identifying enemy disposition info based on time limited or partial observations of enemies. If all Marines had cameras, UxS could process distributed enemy disposition data and communicate it to all FT members.
			(A.2.E.2) Enemy fires (heavy weapons locations, fires locations, locus of fires, accuracy of fires, volume of fires)	The effectiveness of enemy fires (are enemy fires accurate enough and of sufficient volume to prevent friendly movement) is the root purpose of this subtask.									Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
			(A.2.E.3) Enemy fields of fire	What areas are enemy weapons capable of affecting? Are they firing into those areas? If not, may indicate effective suppression.									Directability: FT members need capability to communicate enemy coverage information to UxS & vice versa. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Overlaying of enemy fires onto terrain/obstacles. Combines A.2.E.1-2 with A.2.TW.1-2. Bordering on level 2 SA. Can be translated to safe corridors where enemy fields of fire don't exist. This is an area where UxS could significantly assist FT by determining what areas are covered by enemy weapons, calculating optimal cover locations & paths of movement then communicating that info to Marines. This may be difficult to display due to complexity of the information. Probably not fully realizable without some form of heads up display.
			(A.2.TW.1) Type of terrain (hilly, flat, mountainous, urban)	Does terrain type affect suppression? Is suppressor accounting for terrain type (ballistics of uphill/downhill shooting etc.)?									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area.

(A.2.TW.2) Terrain features (obstacles, enemy cover)	Do terrain features affect suppression? Is suppressor accounting for terrain features? Example: if an enemy is behind a low concrete wall, is the suppression aimed at the correct spot IOT keep enemy's head down?	Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
(A.2.TW.3) Enemy fields of observation	What can enemies see?	Overlaying of enemy disposition onto terrain/obstacles. Combines A.2.E.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire.
(A.2.TW.4) Friendly fields of observation	What can friendlies see?	Overlaying of friendly disposition onto terrain/obstacles. Combines A.2.FTS.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire but easier to calculate.
(A.2.TW.5) Visibility	How far can assessor see? What is the cause of loss of visibility?	Observability: UxS must communicate with FTL when visibility is obscured. . UxS may use sensors that are affected differently than human eyes or Marine sensors. This could lead to unforeseen problems if UxS can see but Marines cannot or vice versa. UxS may require assistance comprehending the cause of visibility loss.
(A.2.TFS.1) Friendly disposition	It is a team task. Must be able to know position relative to FT members and adjacent/higher units.	Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
(A.2.TFS.2) Friendly movement (in relation to suppressive fires)	Who is moving where? Is suppression supporting movers?	
(A.2.TFS.3) Areas/timing/type of planned fires	Is suppression in line with planned fires?	Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: FTL needs capability to confirm UxS receipt of fires plan (ex: "Robot, what is your part of the fires plan?"). Predictability: UxS should have selectable permissions on starting/stopping fire (wait for a Marine to shoot first, cease fire if Marines cease fire, execute fires on order/timing/event, etc.). FTL must assign for UxS (significant potential for interface drain on SA in combat situation). Ideal UxS could interpret aural and visual commands/signals just like Marines. Robot can help FT members keep track of planned fires during execution. Robot could also be central hub for fires alerts coming to team in execution.
(A.2.TFS.4) Areas/timing/type of current fires	Must see fires to assess them.	Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e. RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (e.g., if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression). Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are shooting IOT not interrupt their firing.
(A.2.TFS.5) Direction of fires (other friendlies)	Must be able to judge fire direction to assess them.	
(A.2.TA.1) Planned rate of movement	Interdependence between suppressor and mover	Directability: FTL needs capability to communicate planned rates of movement to UxS. FTL needs capability to order specific rates of movement for UxS. Observability: FTL needs capability to query UxS ability to achieve planned rates of movement. Predictability: UxS needs library of UxS and Marine rates of movement across varying terrain. UxS can assist with countdowns until clear, expected timing of suppression for movement rates and distances, and movement planning to meet time constraints.
(A.2.TA.2) Actual rate of movement	Interdependence between suppressor and mover. Is suppression affecting rate of movement?	Directability: FTL needs to capability to capability to order specific rates of movement for UxS. UxS needs same capability IOT direct FT when they are moving too slow. Observability: FTL needs capability to query UxS reason for slow rates of movement. UxS needs same for Marines. Predictability: UxS needs to either visibly adjust speed of movement when directed or return a response as to why it cannot. Comparison between Friendly movement (A.2.TFS.2) and Planned rate of movement (A.2.TA.1) IOT determine delta between planned and actual rate of movement. Subjective comparison with enemy fires provides insight into whether friendly rate of movement is being impeded by enemy fires, in which case suppression is ineffective. This is a judgement call. There could be other reasons for delta (fatigue, unexpected difficult terrain, etc.). UxS should be able to use volume and accuracy of enemy fires to assess if fires are a significant factor affecting rate of movement. Confirmation by FT members would increase

					reliability of UxS assessment (opportunity for machine learning that improves assessment)
			(A.2.S.1) Areas of operation/boundaries	Context: how do FT & task fit into and affect larger/adjacent units & tasks? Must adhere to boundaries during task & subtask.	Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
	(A.3) Adjust fires as necessary. Adjusting fire onto a target is a fire control method that can be initiated by a unit leader's command or an individual Marine when the previous target has been effectively engaged or a higher priority target is presented.	Assessor: -Communicate adjustments to suppressor Suppressor: -Receive adjustments from assessor -Aim weapon -Fire weapon	Repeat (A.1) "Suppress the enemy" SA requirements	If suppression is ineffective, the suppressor must adjust fire. If suppression is effective, the assessor transitions to subtask A.4.	Receiving/passing assessment and intentions to teammates - team behaviors that convey intentions. Confirmation that OPD is occurring both to/from UxS.
	(A.4) Identify next covered position. Cover is protection from enemy fire whereas concealment only provides protection from enemy observation. Terrain features that offer cover also provide concealment. Cover can be natural or manmade. Natural cover includes logs, trees, stumps, ravines, hollows, reverse slopes, and so forth. Manmade cover includes fighting holes, trenches, walls, rubble, abandoned equipment and craters. Even the smallest depression or fold in the ground (e.g., micro-terrain) gives some cover. ***This subtask is tightly coupled to subtask A.2 Assess effect of fires. Assessment of suppression informs selection of cover and selection of cover informs assessment of suppression.	-Identify objects/terrain -Compare size of objects to self -Assess material properties of cover	(A.4.M.1) Mission objective	Context: what is the larger mission objective and how does movement support mission objective? At minimum, FT must understand the next higher level (squad) task.	Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc.). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.4.M.2) Location of objective	What general directions should FT move?	Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.4.M.3) Commander's intent	Should FT deviate from SOM IOT achieve Cdr's intent?	Machines may never understand this, or at least take a long time
			(A.4.M.4) Course of action / scheme of maneuver	Context: What specific path of travel should FT move? Next cover must fit into scheme of maneuver	Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.4.E.1) Enemy disposition (location, dispersion, numbers, weapons)	Need to know where enemy are located in order to choose cover. Cover is always enemy oriented.	Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed

													directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
			(A.4.E.2) Enemy fields of fire	Cover should be chosen based on its projected effectiveness at protecting FT from enemy fields of fire. Path of travel to cover should avoid fields of fire when possible.									Directability: FT members need capability to communicate enemy coverage information to UxS & vice versa. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Overlaying of enemy fires onto terrain/obstacles. Combines A.2.E.1-2 with A.2.TW.1-2. Bordering on level 2 SA. Can be translated to safe corridors where enemy fields of fire don't exist. This is an area where UxS could significantly assist FT by determining what areas are covered by enemy weapons, calculating optimal cover locations & paths of movement then communicating that info to Marines. This may be difficult to display due to complexity of the information. Probably not fully realizable without some form of heads up display.
			(A.4.TW.1) Type of terrain (hilly, flat, mountainous, urban)	Does terrain provide cover? How much cover generally exists? What is the general quality of cover? How will terrain affect movement to cover?									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal. Assessment of terrain feature material properties (suitability as cover) is much harder than pattern matching different shapes. UxS must learn to recognize which features are suitable cover and which are not. Material type, size, thickness, age, position, etc. are all factors in assessing cover.
			(A.4.TW.2) Terrain features (obstacles, enemy cover)	Must assess suitability of features as cover									
			(A.4.TW.3) Enemy fields of observation	Can enemy see cover and path to cover?									Overlaying of enemy disposition onto terrain/obstacles. Combines A.2.E.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire.
			(A.4.TW.4) Friendly fields of observation	Can friendlies see cover and path to cover (avoid friendly fire but also need suppression from friendlies)									Overlaying of friendly disposition onto terrain/obstacles. Combines A.2.FTS.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire but easier to calculate.
			(A.4.TW.5) Visibility	How far away can cover be seen?									Observability: UxS must communicate with FTL when visibility is obscured. . UxS may use sensors that are affected differently than human eyes or Marine sensors. This could lead to unforeseen problems if UxS can see but Marines cannot or vice versa. UxS may require assistance comprehending the cause of visibility loss.
			(A.4.TFS.1) Friendly disposition	Where is everyone else? Is cover selection supportable by friendlies and will it support their subsequent movement?									Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
			(A.4.TFS.2) Areas/timing/type of planned fires	Don't choose cover that is about to take friendly fire.									FTL must assign for UxS (potential for interface drain on SA in combat situation). Ideal UxS could interpret the same aural and visual commands that Marine teammates receive. ADDRAC format?
			(A.4.TFS.3) Direction of fires (other friendlies)	Don't choose cover that is currently taking friendly fire or would require travel through friendly fire									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e. RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (e.g., if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression).

					Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are shooting IOT not interrupt their firing.
			(A.4.S.1) Areas of operation/boundaries	FT must stay within required boundaries	Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
	(A.5) Move to next position under the cover of suppression. High crawl is used to gain ground and to be able to access weapon if needed, especially when under sporadic fire or when negotiating low obstacles. Low crawl is used when under intense fire or for negotiating low obstacles. Rushes are used in short intervals to covered and concealed positions. Marines must limit the length of their rushes to distances that will enable their buddy to continue engaging the enemy (e.g., outside of 300 mil) If no covered position is available, the "low crawl" individual movement technique should be used.	-Physically move -Maneuver around obstacles -Maneuver around friendly forces without obstructing fires -Get behind cover	(A.5.M.1) Mission objective	Context: what is the larger mission objective and how does movement support mission objective? At minimum, FT must understand the next higher level (squad) task.	Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc.). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.5.M.2) Location of objective	What general directions should FT move?	Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.5.M.3) Commander's intent	Should FT deviate from SOM IOT achieve Cdr's intent?	Machines may never understand this, or at least take a long time
			(A.5.M.4) Course of action / scheme of maneuver	Context: What specific path of travel should FT move? Next cover must fit into scheme of maneuver	Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.5.E.1) Enemy disposition (location, dispersion, numbers, weapons)	Need to know where enemy are located in order to choose cover. Cover is always enemy oriented.	Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
			(A.5.E.2) Enemy fires (heavy weapons locations, fires locations, locus of fires, accuracy of fires, volume of fires)	Where are fires coming from and what are characteristics? Affects path of movement	Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS

		must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
(A.5.E.3) Enemy fields of fire	What areas are enemy weapons capable of affecting? Ideal path of movement avoids fields of fire.	Directability: FT members need capability to communicate enemy coverage information to UxS & vice versa. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Overlaying of enemy fires onto terrain/obstacles. Combines A.2.E.1-2 with A.2.TW.1-2. Bordering on level 2 SA. Can be translated to safe corridors where enemy fields of fire don't exist. This is an area where UxS could significantly assist FT by determining what areas are covered by enemy weapons, calculating optimal cover locations & paths of movement then communicating that info to Marines. This may be difficult to display due to complexity of the information. Probably not fully realizable without some form of heads up display.
(A.5.TW.1) Type of terrain (hilly, flat, mountainous, urban)	How does terrain affect movement?	Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
(A.5.TW.2) Terrain features (obstacles, enemy cover)	Must avoid features that impede travel.	
(A.5.TW.3) Enemy fields of observation	Can enemy see movement?	Overlaying of enemy disposition onto terrain/obstacles. Combines A.2.E.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire.
(A.5.TW.4) Friendly fields of observation	Can friendlies see movement?	Overlaying of friendly disposition onto terrain/obstacles. Combines A.2.FTS.1 with A.2.TW.1-2. Bordering on level 2 SA. Similar to (A.2.E.3) Enemy fields of fire but easier to calculate.
(A.5.TW.5) Visibility	How far away can cover be seen?	Observability: UxS must communicate with FTL when visibility is obscured. . UxS may use sensors that are affected differently than human eyes or Marine sensors. This could lead to unforeseen problems if UxS can see but Marines cannot or vice versa. UxS may require assistance comprehending the cause of visibility loss.
(A.5.TFS.1) Friendly disposition	Where is everyone else? Will movement affect them?	Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
(A.5.TFS.2) Areas/timing/type of current fires	Must know fires layout to safely maneuver through them.	Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e. RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (e.g., if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression). Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are
(A.5.TFS.3) Direction of fires (other friendlies)	Don't move through friendly fire	

					shooting IOT not interrupt their firing.
			(A.5.S.1) Areas of operation/boundaries	FT must stay within required boundaries	Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
	(A.6) Identify your target and continue suppression to allow buddy to move to next covered position.		Repeat (A.1) "Suppress the enemy" SA requirements		
	(A.7) Repeat until steps 1-5 until the objective is reached.		Repeat (A.1) through (A.5) SA requirements		
	(A.8) Execute actions on the objective. Primarily a function for contact, security, or reconnaissance patrols. Within the ground attack context, actions on the objective are limited to physically occupying the entire objective area in such a manner that Marines "assault through" the objective, as opposed to just "reaching" the objective.	-Maintain on-line formation with FT (UxS may be incapable of maintaining necessary rate of movement with Marines during this subtask even if able to support other subtasks due to necessity to keep formation with Marines). -Aim weapon. -Fire weapon.	(A.8.M.1) Mission objective	Actions on the objective entails achieving the mission objective. Most critical sub-task for this SA requirement	Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. Interface examples: Mission map interface with standard military ops terms & graphics would allow FTL to confirm robot has downloaded mission parameters. Map walkthrough played by robot would confirm for FTL that robot understands the intended COA. Read back or visual display of mission parameters and constraints would allow FTL to confirm robot settings are correct for mission (ROE, weapon conditions, information requirements, etc.). AAR & RIF can assist with orders process if they have ability to interface with UxS (this may depend on system security, access permissions, and chain of command programming).
			(A.8.M.2) Location of objective	Need to reach the objective to execute.	Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.8.M.3) Commander's intent	Context: why conduct this mission? Cdr's intent may drive different actions upon reaching objective than originally planned.	Machines may never understand this, or at least take a long time
			(A.8.M.4) Course of action / scheme of maneuver	What is the plan for actions on the objective?	Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.8.M.5) Priority of targets	Priorities during actions on objective.	Directability: FTL needs capability to communicate target priorities to UxS. Observability: FTL needs capability to confirm UxS receipt of priorities. Predictability: Confirmed when UxS selects targets based on priorities. Achieved through training/experience with dynamic targets of varying priorities. Doctrinal for human AR. Current UxS could be programmed with priority targets but may struggle with application during execution. If machine can identify and distinguish targets by function/capability, it could execute this task with less or without assistance. Machine learning can overcome ability to identify enemy uniforms, vehicles, weapon systems visually/aurally. If machine could assess priority targets during execution and had access to distributed target data or camera feeds from other team members, could dramatically assist with assessing priority targets based on larger picture of the whole team.

			(A.8.M.6) Assignment of targets	Are target assignments specific or general (lanes, sectors, etc.)?									Directability: FTL needs capability to assign targets to UxS. Observability: FTL confirms receipt of target assignment by observing UxS fires - no different than with Marine. Predictability: Built through training and experience of target assignment & resultant actions. UxS should expect target assignments from FTL & needs to monitor FTL for assignments/updates during actions. If machine could process enemy targets, friendly locations, boundaries, COAs, etc. then machine may be able to optimize target assignments and feed info to other members. If UxS is currently incapable of identifying targets and implementing target assignments independently, a "gun buddy" UxS that follows a particular Marine and shoots what that Marine shoots may achieve intermediate progress (could be conducting machine learning for future capability at same time). Gun buddy UxS could feed Marine information from its sensors through various heads up interfaces that could support a hybrid Marine/machine buddy team that optimizes combination of robotic gains with Marine cognition and decision-making. Every FT member is engaged, and there is less explicit coordination of fires due to the pop-up nature of targets. Target acquisition and reaction must be automatic to be useful.
			(A.8.E.1) Enemy disposition (location, dispersion, numbers, weapons)	Actions on objective when assaulting enemy position involve destruction of enemy. Must locate first.									Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines.
			(A.8.E.2) Enemy fires (heavy weapons locations, fires locations, locus of fires, accuracy of fires, volume of fires)	Enemy fires must be responded to immediately during actions on objective. Priorities of targets is tightly coupled to this SA requirement.									Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
			(A.8.TW.1) Type of terrain (hilly, flat, mountainous, urban)	How does terrain affect movement?									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
			(A.8.TW.2) Terrain features (obstacles, enemy cover)	Must avoid features that impede travel. Check all features that could provide enemy cover and concealment.									
			(A.8.TW.3) Visibility	How far away can enemies be seen?									Observability: UxS must communicate with FTL when visibility is obscured. . UxS may use sensors that are affected differently than human eyes or Marine sensors. This could lead to unforeseen problems if UxS can see but Marines cannot or vice versa. UxS may require assistance comprehending the cause of visibility loss.
			(A.8.TFS.1) Friendly disposition	Where is everyone else? Actions on objective involves close, concerted movement with simultaneous fires. Friendlies are now in very close proximity to enemy forces.									Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should

													process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
			(A.8.TFS.2) Areas/timing/type of current fires	Must know fires layout to safely maneuver through them.									Directability: FTL needs capability to communicate fires plan to UxS. UxS needs capability to communicate updates to FTL. Observability: UxS needs capability to perceive current fires characteristics and directions. Predictability: UxS should communicate to FTL when current fires do not match fires plan. UxS should not fire on targets that Marines are already engaging unless specifically directed to do so or if there is a target mismatch (conflict with priority of fires or assignment of targets, i.e. RIF is engaging enemy machine gun nest and UxS is engaging enemy rifleman. If FTL does not reassign targets, team communication would be needed between UxS and RIF to sort out). UxS should predict fires timing based on plan (e.g., if suppression will end before UxS can cross open terrain, best decision may be to hold current position until next round of suppression). Weapon aim point and fire status trackers could feed data to UxS. Robot should indicate perception of friendly fires by always moving behind Marines who are shooting IOT not interrupt their firing.
			(A.8.TFS.3) Direction of fires (other friendlies)	Don't move through friendly fire. Don't impede friendly fires.									
			(A.8.S.1) Areas of operation/boundaries	FT must stay within required boundaries									Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
	(A.9) Consolidate. Consolidation facilitates the rapid reorganization of a hasty defense to permit the attacking unit to hold the objective just seized in the event of an enemy counter attack. Consolidation/ Reorganization 1) prepares for the enemy's counter attack 2) reestablishes command and control within the unit 3) reestablishes communications with higher 4) addresses casualties/ammo 5) prepares to resume the attack/pursue the enemy. Security, Automatic Weapons, Fields of Fire, Entrench (SAFE) describes the priorities of work during the initial phase of establishing a hasty defense and is a guideline for the seamless transition from the offense to the occupation of the defense.		(A.9.M.1) Mission objective	Consolidation occurs after mission objective is achieved.									Directability: FTL needs capability to issue orders to UxS. AR and UxS may receive orders from higher levels of chain of command for efficiency reasons, but at minimum FTL needs capability. Observability: FTL needs capability to confirm UxS receipt of orders Predictability: FTL needs capability to assess UxS comprehension of orders. True understanding of the objective may be extremely difficult for a machine. Use of OSMEAC mission order format, tactical tasks (seize, screen, destroy, etc.) and success criteria (1st platoon occupies hill 512, 25% of enemy armor assets K-kill, etc.) will allow machine to "understand" mission objective. Mission orders received via chain of command through FTL, but AR may assist with interpretation of mission orders. UxS incapable of that assistance role - mission parameters must be programmed. UAS equipped UxS could significantly enhance ability to confirm mission objective achievement.
			(A.9.M.2) Location of objective	Consolidation occurs relative to the objective location.									Directability: FTL needs capability to communicate objective location to UxS. Observability: FTL needs capability to confirm UxS receipt of absolute/relative objective location. Predictability: FTL needs capability to assess UxS navigable routes to objective location. Robot can't know until programmed but once programmed it can track objective location better than Marines and assist team with navigation. UxS could plot possible routes that are navigable by UxS and humans (dependent on quality of navigation system data and navigability programming).
			(A.9.M.3) Commander's intent	Context: why conduct this mission?									Machines may never understand this, or at least take a long time
			(A.9.M.4) COA	Context: how does this task fit into scheme of maneuver?									Directability: FTL needs capability to communicate COA to UxS. Observability: FTL needs capability to confirm UxS receipt of COA. Predictability: FTL needs capability to assess UxS understanding of COA (i.e., COA impact on route selection, navigability of COA routes, etc.). May be similar to boundaries in terms of machine tacking of COA, but these are soft guidelines, not hard rules like boundaries. COAs are oftentimes communicated visually through ops terms and graphics on a map or imagery. Could be implemented with software that interprets ops terms and graphics drawn onto a touchscreen map interface, but interpretation of physical maps/imagery with COA diagrams would be ideal.
			(A.9.E.1) Enemy disposition (location, dispersion, numbers, weapons)	Where are enemy forces now? Primary concern is reattack.									Directability: FT members need capability to communicate enemy fires updates to and receive the same from UxS. FT members need capability to pass directive corrections to UxS suppressor based on enemy fires weighed against needs of the assessor. This may be more difficult for UxS to direct FT members. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Predictability: If FT member is firing at enemy assume it is seen. Otherwise, communicate any enemy disposition info that has not already been passed. UxS must be programmed to request assistance/confirmation when unsure if object of interest is an enemy. Dependent on hostile fire detection system for UxS. HFI systems exist - actual efficacy would need to be evaluated. If good enough machine capability might be more accurate assessment of volume and accuracy than current human subjective assessment. Locating enemy fires sources is one area a UxS could offer significant improvements over Marines, but the communication of that information between team members will likely be harder for the UxS than for Marines. Marines have significant common language to fall back on for detailed directions. The fallback for the UxS is always to mark the target by fire, but in the end the UxS has more limited capabilities in communication than the Marines. Assessment of the effectiveness of enemy fires is highly subjective. While a UxS

													may be able to more precisely quantify the volume and accuracy of enemy fires, the comprehension part of those fires may be difficult. UTACC should focus on defining metrics for the UxS to comprehend enemy fires effectiveness against itself before it tries to comprehend the same for humans. The UxS metrics could use caliber, proximity, volume, and movement projections to try to determine if enemy fires will affect its next movement. This is highly coupled with the choice of next cover location (subtask A.4).
			(A.9.E.2) Enemy reinforcement availability	Prepare for counterattack									Coupled with A.9.E.1 Enemy disposition. Requires DRAW-D comprehension and EMLCOA/EMDCOA projection. UxS could provide big data based assessments of likelihood of reattack or possible avenues of attack. Could greatly assist FTL consolidation decisions. Link back to higher could provide 2-way improvements to accuracy of post mission assessments and pushing of counterattack indications to the right people. Good opportunity for UxS to scout while Marines rest.
			(A.9.TW.1) Type of terrain (hilly, flat, mountainous, urban)	Defensibility of location? Choose best location to defend enemy counterattack.									Directability: FT members need capacity to communicate navigability assessment to UxS & vice versa. Utilize OCOKA format & ops terms and graphics. Observability: UxS needs capability to "learn" human navigability capacity by observing Marines (machine learning). Predictability: UxS needs set of robot & human terrain navigability parameters in order to understand impact of terrain on itself & Marines. UxS must communicate when it cannot traverse or needs assistance to traverse area. Stored 3D map data & real-time sensing dependent. Sensor FOV & fidelity may significantly affect real-time input scope (how far out can UxS assess terrain obstacles, resolution, type of sensor used, etc.). UxS could assist with route planning based on navigation data during mission planning or when plans change. Active sensors such as LiDAR or MMW RADAR have drawbacks associated with EM radiation. Passive means through machine vision interpretation would be more ideal.
			(A.9.TW.2) Terrain features (obstacles, enemy cover)	Where is cover at location?									
			(A.9.TFS.1) Friendly disposition	Must locate and consolidate friendlies.									Directability: FT members need capability to communicate friendly disposition updates to and receive the same from UxS. Observability: UxS must be able to acknowledge receipt of info & understand same acknowledgement from Marines. Marines need observability that UxS perceives them. Predictability: Communicate friendly disposition updates only if requested or FT member's current or predicted actions will be impacted by info & friendlies are not within that member's FOV. UxS must be programmed to request assistance/confirmation when unsure if object of interest is friendly. Utilize higher, adjacent, support, and attachment/detachment labels to categorize command & physical relationships. Currently possible through tracking of friendlies via GPS, radios, etc. Passive tracking of friendlies would be ideal state to avoid EM emissions. System should process recent disposition data against COA to project expected friendly movement. Observability of UxS perception of Marines will be a challenge - trusting that a heavy UxS perceives a Marine with enough precision that it won't run the Marine over when joining the Marine behind a piece of cover may take some significant evaluation of different methods. Design example: UxS could indicate its comprehension and projection of friendly movement by changing weapon muzzle direction when friendlies are about to cross in front of its weapon.
			(A.9.S.1) Areas of operation/boundaries	FT must stay within required boundaries									Directability: FTL needs capability to communicate AO/boundaries to UxS. Observability: FTL needs capability to confirm UxS receipt of AO/boundaries. Predictability: FTL needs capability to assess UxS actions relative to AO/boundaries. AOs & boundaries can be identified by grid coordinates, descriptions of terrain features, or ops terms and graphics depicted on a map/imagery. Straight boundaries between grid coordinates are easily received by machines, interpretation of ops terms and graphics and correlation of physical maps/imagery to navigation software will take time. UxS may be able to overcome this with machine learning focused on interpretation of different coordinate systems and standard map/imagery layouts. Robot can't know them until programmed but once programmed it can track boundaries better than Marines and assist team with adherence. UxS may need to understand different actions for different boundaries: do not cross, do not fire across (or do not fire across without higher permission/coordination), communicate passage of boundaries, etc.
			(A.9.L.1) Ammunition level	Rearming time.									Directability: FTL needs capability to dictate ammunition conservation. Observability: FTL needs capability to observe UxS ammunition level. Utilize standard prowords "Shotgun," "Winchester," etc. to indicate particular ammunition states Predictability: FTL needs to capability to select actions/settings based on ammunition level (ex: at "Shotgun" request resupply & at "Winchester" move to AAR for reload assistance). If machine could track team's ammunition and alert members when to change mags before certain pushes, etc. They can also alert logistics quickly and automatically that team needs resupply.
			(A.9.L.2) Supply level	Resupply time.									Same considerations as A.9.L.1 Ammunition level. Marines: chow, water, batteries UxS: fuel, fluid, battery level
			(A.9.L.3) Weapon/equipment status	Repair time.									Same considerations as A.9.L.1 Ammunition level. Assumes UxS can function check weapon
			(A.9.L.4) Number/severity of casualties	Locate, assess, and treat casualties.									Directability: FTL needs capability to communicate biometric status of FT members to FTL. Observability: FTL needs capability to monitor FT member biometrics. Predictability: FTL needs library of FT member biometrics IOT assess current status. Personalized situational metrics that would trigger UxS alert to FTL. UxS may be able to monitor FT biometrics via sensors. Unlikely to be able to diagnose battlefield injuries fully however.
			(A.9.L.5) Medical treatment/evacuation plan	What procedures should be followed for casualties?									Relayed through orders process. Must be programmed into UxS. UxS is unlikely to be able to execute these tasks, but could assist FLT in remembering procedures and coordination with higher. Opportunity exists to automate some

			(A.9.L.6) Enemy prisoner of war plan	What should be done with EPWs?									functions that UxS can handle.

IA SA table task and subtask descriptions are doctrinal. Sources: USMC (n.d.), USMC (2002), and USMC (2016).

APPENDIX F. REPRESENTATIVE LIST OF SA QUESTIONS

- Do members begin with common baseline (expand this)?
  - Do they know their differences?
  - Do they trust novices to seek SA assistance (does robot recognize when it doesn't know something)?
- Who should notice?
- Do they notice?
  - Does team member back up occur?
- Is perception accurate?
- What level of SA is achieved?
  - Why? (incomplete info, lack of understanding, etc.)
- Do they send communication?
  - How do they communicate?
  - Does appropriate communication procedure exist & do they use it?
    - If not, does plain language achieve aims?
  - Should they communicate?
    - Do they recognize the need to communicate?
      - Why/why not?
  - Do they communicate to the right individual?
    - Why/why not?
  - Can they communicate?
- Is information received?
  - Is there a confirmation means?
  - Can it be received?
  - Is it received accurately?
    - If not, why?
      - Failure of common language or shared mental model?
      - Limitations of medium?
        - Does team adapt to limits of medium?
      - Incomplete information?

    - Is it received completely?
        - Does receiver seek clarification?
- Does information add to previous team info?
    - Does synthesis return to other teammates?
    - Do team members understand changes to situation?

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